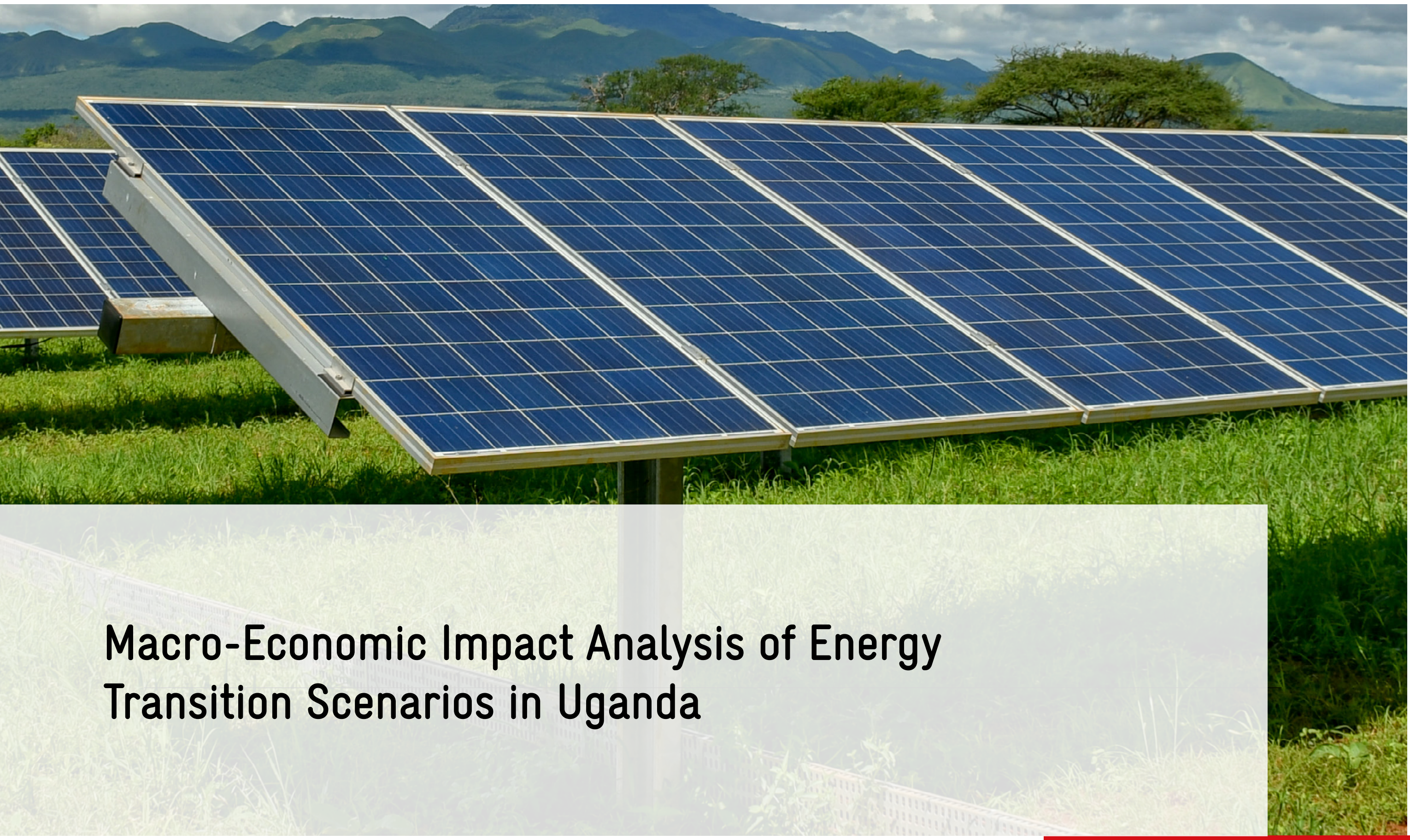

# Macro-Economic Impact Analysis of Energy Transition Scenarios in Uganda

An Economy-Energy-Emissions Model (e3.ug)
Final Report

Supported by:

Federal Ministry
for the Environment, Nature Conservation,
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based on a decision of
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| | |
|---|---|
| AFOLU | Agriculture, Forestry, and Other Land Use |
| BAU | Business-as-usual |
| BMU | German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety |
| Bn | Billion |
| CEPP | Current energy policy planning |
| $CH_4$ | Methane |
| $CO_2$ | Carbon dioxide |
| $CO_2e$ | Carbon dioxide equivalent |
| CRED | Climate resilient economic development |
| DIOM-X | Dynamic Input-Output Model in Excel |
| E3 | Economy-Energy-Emission |
| EE | Energy efficiency |
| ERA | Electricity Regulatory Authority |
| GDP | Gross Domestic Product |
| GHG | Greenhouse gas emissions |
| GINFORS_E | Global INterindustry FORecasing System – Energy |
| GIZ | Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH |
| GWS | Gesellschaft für Wirtschaftliche Strukturforschung (GWS) mbH / Institute of Economic Structures Research |
| ICS | Improved cookstoves |
| IEA | International Energy Agency |
| IMF | International Monetary Fund |
| INDC | Intended Nationally Determined Contribution |
| IO | Input-Output |
| IOT | Input-Output table |
| IRENA | International Renewable Energy Agency |
| KG | Kilogram |
| KTOE | Kiloton oil equivalents |
| KW | Kilowatt |
| KWH | Kilowatt hour |
| LEAP | Low Emissions Analysis Platform |
| LPG | Liquefied Petroleum Gas |

| | |
|---|---|
| LTS | Long-term strategy |
| M&I | Manufacturing and installation |
| MEMD | Ministry of Energy and Mineral Development |
| MENA | Middle East and North Africa |
| Mn | Million |
| MW | Megawatt |
| MWE | Ministry of Water and Environment |
| MS | Microsoft |
| $N_2O$ | Nitrous oxide |
| NDC | Nationally Determined Contributions |
| NDP | National Development Plan |
| NPISH | Non-profit institutions serving households |
| O&M | Operation and maintenance |
| PV | Photovoltaic |
| RE | Renewable Energy |
| SOCLIMPACT | DownScaling CLImate imPACTs |
| SNA | System of National Accounts |
| TFEC | Total Final Energy Consumption |
| Tn | Trillion |
| TOPDAD | Tool-supported Policy Development for regional Adaptation |
| U4RIA | Ubuntu, Retrievability, Reusability Repeatability, Reconstructability, Interoperability and Auditability |
| UBOS | Uganda Bureau of Statistics |
| UETCL | Uganda Electricity Transmission Company Limited |
| UG | Uganda |
| UGX | Uganda shilling |
| UN | United Nations |
| UNFCCC | United Nations Framework Convention on Climate Change |
| USD | US-Dollar |
| VBA | Visual Basic for Applications |

# SUMMARY

The Ministry of Energy and Mineral Development of Uganda states in its updated energy policy that achieving the right balance between energy, economy and the environment leads to sustainable development (MEMD 2019, p. 7). As signatory to the United Nations Framework Convention on Climate Change and the Paris Agreement, this priority is reflected in the country's climate policy as well. As per its first Nationally Determined Contributions (NDC) in 2016 and its updated NDC in 2022, Uganda aims to implement climate mitigation measures amongst others in the energy and forestry sectors (MWE 2015, 2022). Uganda strives to reach a total renewable energy capacity of at least 4,575 MW by 2040 (MWE 2015; MEMD 2022b). The mitigation potential of expanding RE capacity in the energy sector is significant, considering the possible offsetting of wood and charcoal burning and the resulting deforestation (MWE 2015).

The implementation of the envisaged "energy transition" towards electricity from renewable energy sources and energy efficiency improvements are expected to exhibit various benefits for single sectors and the whole economy which can be detected by and analysed with an environmentally extended economic model, a so-called E3 model (economy, energy, emissions). It allows for discovering not only obvious direct impacts but also impacts stemming from second round effects and feedback loops. This integrated modelling approach of the 3Es in one model framework assures a consistent view of possible transition pathways in Uganda.

Such a model – the e3.ug – was built for Uganda. It is a projection and simulation model which was developed to evaluate the macroeconomic impacts of energy policies for every year until 2050. Each of the three model parts is based on a rich and up-to-date dataset given (as far as possible) as time series on an annual basis which allows for deriving model relationships empirically. The business-as-usual (BAU) scenario extrapolates the relationships observed in the past into the future under consideration of exogenous developments retrieved from other sources such as population and oil price development. The business-as-usual scenario is not to be interpreted as a projection in terms of the most realistic development. It serves as a benchmark to compare model results of policy scenarios. Thus, a further expansion of renewable energy generation capacities is not foreseen, and energy efficiency improvements remain low in the business-as-usual scenario.

Scenario analysis is used to analyse the macroeconomic impacts of energy policies or any other policies. Such policies must be translated into quantified changes of model variables. These initial impacts cause chain reactions in the e3.ug model. To see the effects of a policy, the policy scenario is compared to the business-as-usual scenario that does not contain the assumptions on the respective policy measure. The resulting deviations for various model variables, e. g., GDP, sectoral employment and production can be interpreted as impacts of the examined policy („what-if" analysis). The e3.ug model was used to analyse, for example, the impacts of a "renewable energy expansion" scenario and an "energy efficiency improvement" scenario.

The “renewable energy expansion” scenario fulfils the plan of the Ugandan government to increase the installed renewable energy capacity to 4,575 MW by 2040. In particular, hydro power capacity will be expanded but also solar PV, wind and geothermal energy will receive attention. Electricity from renewable energy replaces generation from oil products and unsustainable biomass. The scenario results indicate that renewable energy expansion will benefit Uganda economically, socially, and environmentally However, RE expansion comes at costs which should be at least partially covered by the government and / or international donors to regulate electricity price increases. To exploit the full benefits, an increased use of “green” electricity should be promoted and financially supported.

The “clean cooking” scenario shows that increased electricity consumption for cooking at the expense of biomass has positive effects on human health and on the environment. However, these are curtailed in the case of using liquefied petroleum gas for cooking.

The ”energy efficiency improvement” scenario assumes that further potentials for biomass and electricity savings are possible for several sectors of the economy. With moderate expectations, electricity savings of up to 16% are economically achievable for the residential, commercial, and industrial sector by 2030. In the energy sector, further reduction of transmission and distribution losses to 15.3% by 2030 are expected. Biomass savings of 35% to 50% are possible from improved cookstoves. 10% of all private households and institutions are expected to adopt them by 2025. The implementation of the envisaged efficiency improvements is expected to be beneficial for economic growth, employment, and the environment. Although efficiency gains involve additional costs that will be offset in the medium to long term, the investments must be realized now. Financial support especially for vulnerable households can foster dissemination of improved cookstoves.

# 1 INTRODUCTION

## MACROECONOMIC IMPACTS OF ENERGY TRANSITION SCENARIOS IN UGANDA

The Ministry of Energy and Mineral Development (MEMD) of Uganda states in its updated energy policy that achieving the right balance between energy, economy and the environment leads to sustainable development (MEMD 2019, p. 7). As signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, this priority is reflected in the country's climate policy as well. As per its Intended Nationally Determined Contribution (INDC), officially submitted as the first NDC in 2016 and its updated NDC in 2022, Uganda aims to implement climate mitigation measures amongst others in the energy and forestry sectors (MWE 2015, 2022). Uganda strives to reach a total renewable energy (RE) capacity of at least 4,575 MW by 2040 (MEMD 2022b). The mitigation potential of expanding renewable energy (RE) capacity in the energy sector is significant, considering the possible offsetting of wood and charcoal burning and the resulting deforestation (MWE 2015). In addition, the use of expensive and polluting generators (powered with diesel and heavy fuel oil) is planned to be reduced with the construction of enabling infrastructure for the electricity sector development (MWE 2015). Between 2002 and 2021, electricity access increased from 5% to 58% (MEMD 2022a).

The implementation of the envisaged "energy transition" is expected to exhibit various benefits for single sectors and the whole economy which can be detected by and analysed with an environmentally extended economic model, a so-called E3 model (economy, energy, emissions). It allows for discovering not only obvious direct impacts but also impacts stemming from second round effects and feedback loops. This integrated modelling approach of the 3Es in one model framework assures a consistent view of possible transition pathways in Uganda.

E3 models, in combination with scenario analysis, are considered appropriate tools[1] to study the economic impacts of both climate protection and climate change adaptation measures. In cooperation with MEMD, the Uganda Bureau of Statistics (UBOS), national modelling consultants and other local experts, the Excel-based model e3.ug for Uganda has been developed.

Jointly with the experts, "energy transition" scenarios were designed and implemented into e3.ug which then simulates the macroeconomic impacts (e. g., changes in economic indicators such as GDP and employment). The openness and flexibility of the e3.ug model allows also for further analyses e. g., the impacts of the Russian-Ukrainian war or the COVID-19 pandemic.

GWS (Institute of Economic Structures Research) has a long history in modelling the economic impacts from renewable energy and energy efficiency for European countries[2], the MENA region[3], Asian countries[4] and at global level with the model GINFORS_E (Global INterindustry FORecasing System – Energy[5]). More

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[1] See https://web.jrc.ec.europa.eu/policy-model-inventory/ for a comprehensive model overview applied for energy and climate policy questions at EU level.

[2] E. g., in Germany with the model PANTA RHEI, in Austria with the model e3.at

[3] E. g., Lebanon, Tunisia, Algeria

[4] E. g., Russia, Georgia, Kazakhstan

[5] https://web.jrc.ec.europa.eu/policy-model-inventory/explore/models/model-ginfors-e

recently, a focus has also been set to the economic impacts of climate change and adaptation (e. g., https://soclimpact.net, http://www.topdad.eu, CRED project).

This report describes the e3.ug modeling approach (section 1.2) and how to conduct scenario analysis (section 1.3) with it. Chapter 1.4 describes in a nutshell the assumptions and results of the business-as-usual scenario, which serves as a basis for the "energy transition" scenarios. Different policy scenarios regarding renewable energy expansion and energy efficiency improvement have been developed. The assumptions, results and conclusions are presented in the subsections of chapter 3. Chapter 4 draws lessons learned and future applications of the e3.ug model.

## E3.UG MODELING APPROACH

The e3.ug model covers the structure of the Ugandan economy and its main connections to the environment, i.e. the use of energy resources and $CO_2$ emissions into the environment. It enables the user to calculate impacts for the whole economy (e. g., GDP) and single economic sectors (e. g., production in agriculture) as well as to draw conclusions on social balance (e. g., employment) and environmental impacts (e. g., emissions).

Figure 1 briefly shows the three model parts and their interrelations. Number 1 indicates the economic core of the E3 model, number 2 shows the energy module and number 3 the emission module.

Each of the three parts is based on a rich and up-to-date dataset on an annual basis. The economic part of the model is built from one IO table and the national accounts (macroeconomic data) plus population and labour market data such as employment, labour force and the average wage rate. Energy balances, which include energy supply, transformation and (final) energy consumption as well as energy prices are at the centre of the energy part. Based on these data in physical units, $CO_2$ emissions can be directly calculated using fixed emission factors.

E3.ug is built upon country-specific data and draws on the observed and theoretical relationships represented as a set of mathematical equations which describe the workings of the Ugandan economy in a simplified way.

Apart from calculations given by definition such as the GDP, which is the sum of consumption, investment and foreign trade, econometric methods and consultation with national experts are used to derive future developments from historical data. A prerequisite is that the annual data is available as time series which allows for deriving model relationships empirically.[6] Different specifications of the regression functions are tested against each other which gives the model an empirical validation. Such a regression equation represents the functional relationship between the model variable to be explained and the influencing model variable(s). Historical, country-specific data are used to verify the regression functions.

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[6] If time series are not available, economic theory and axioms can be used. Various economic theories exist explaining determinants of e. g. macroeconomic consumption on which the model can be built upon. For example, Keynes describes a positive relationship between income and consumption (Keynes 1936).

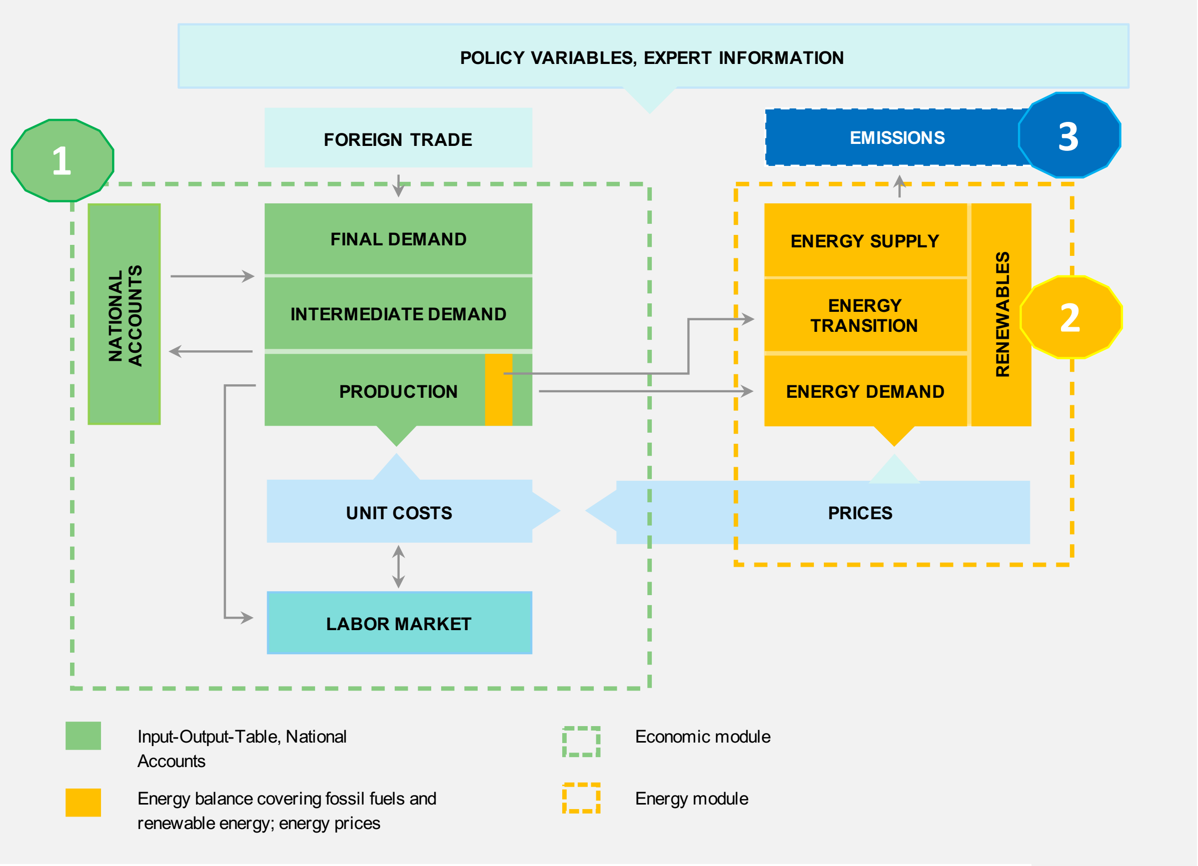

**Figure 1:** E3 model at a glance

Source: own illustration by GWS (2022)

The model results – which depict a possible future pathway of Uganda's economy – depend on a few exogenous inputs (e. g. population growth, world market prices) as well as the modelled relationships within and between the three model parts. Both model data and model calculations have an annual basis for a specified period (e. g., until 2030 or 2050) for which all model variables are simulated. In contrast to static models which compare a situation before and after a change (comparative static analysis), the dynamic simulation model is time-dependent and shows the economic development and transition processes year-by-year.

The e3.ug model is fully developed in Microsoft (MS) Excel using the model building framework DIOM-X. The framework is built upon the Excel built-in programming language Visual Basic for Applications (VBA) and was developed for creating Dynamic Input-Output Models in Excel (DIOM-X; Großmann and Hohmann 2019). The comparatively moderate financial and technical software requirements of the data management and modelling approach allow for designing a sustainable and easily accessible solution (in alignment with the U4RIA goals mentioned under 4.2).

## ECONOMIC MODEL

The core of the E3 model is a macro-econometric (or dynamic) Input-Output model[7]. The underlying modelling approach is based on the so-called Post Keynesian theory: Economic growth is determined from a demand-side perspective. Thus, economic activity is driven by expenditure decisions for consumption purposes of households, investments by companies or export demand from abroad. These are a key determinant of demand, production, and employment.

The model considers the quantity and price relationships at macro level and (scarce) input factors such as labour or energy. While assumed export and import prices rely on exogenous third-party projections (e. g., world market price projections from the International Energy Agency (IEA)), household and government consumption as well as investments are (regression) functions of other model variables and thus determined endogenously within the model. These aggregated macro-values are then distributed to the level of economic sectors by using their shares of the respective variable given from the IO table (top-down approach).

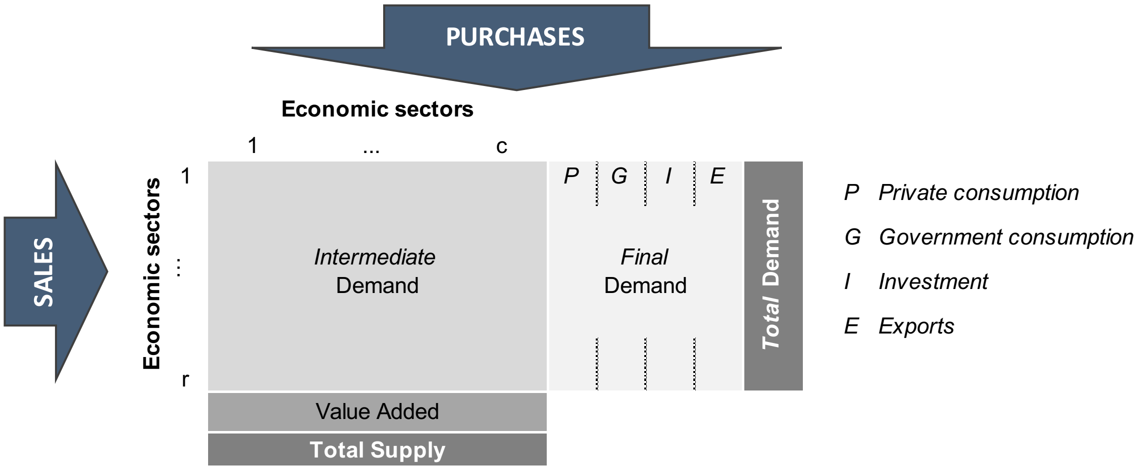

**Figure 2:** Schematic illustration of an IO table

Source: own representation by GWS

The IO table is the main component of this macro-econometric IO model (Figure 2). It shows the key industries, sales, and cost structure (purchases by economic sectors) of the Ugandan economy. The cost structure is represented by the need for input factors (material and energy input) and labour (primary inputs such as compensation for employees which is part of the value added) of each economic sector. Prices are derived by using a unit cost approach considering the various cost components. Labour costs and import prices are influencing factors in the regression functions for the GDP components (consumption, invest-

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[7] Such models exist in different forms and degrees of complexity (see e. g. Eurostat 2008, pp. 527, Stocker et al. [Der Titel „Stocker, Großmann et al. – Sustainable Energy Development in Austria“ kann nicht dargestellt werden. Die Vorlage „Fußnote - Unklarer Dokumententyp - (Standardvorlage)“ beinhaltet nur Felder, welche bei diesem Titel leer sind.], Lehr et al. 2020, Lewney et al. 2019).

ment, etc.) mentioned previously. In contrast to simple static IO models, the volume and price reactions in this macro-econometric IO model are – as far as possible – empirically based and take the forwarding of costs into account.

As prices reflect the cost situation, they do not necessarily and smoothly balance supply and demand. In that sense, the model does not adhere to the equilibrium economics school (unlike the family of CGE models; for conceptual differences see for example Pollitt et al. (2019)). Imbalances between supply and demand are more likely to be offset by (price-dependent) demand-driven effects rather than by price effects. The input coefficients, representing how much and what kind of inputs are needed to produce one unit of a certain good or service, are derived from the IO table and reflect the production technologies. Technological change – induced by e. g., regulatory measures – alters the technology and thus the production structure. For the energy sector, endogenized modelling is pursued by linking the shift from fossil fuels to renewable energy (as given in the energy module) to the input coefficients. Changes in electricity production then lead to changes in the required input of oil products per produced unit of electricity, i.e. the input coefficient oil products and electricity becomes smaller while electricity production remains constant. Also, efficiency gains leading to less energy consumption in the respective industries (modelled in the energy module) are linked to the input coefficients.

The IO model shows the economy-wide (direct and indirect) effects on production caused by demand changes by applying the so-called Leontief[8]-equation, which answers the questions “How does production react when final demand changes? Which industries are affected by these changes?”. Impacts of additional investments (which are part of the final demand, c.f. Figure 2 and Figure 3) in renewable energy and / or energy efficiency are reflected here. Domestic production in the respective industries increases depending on the import-dependencies.

The income-induced effects can be seen in combination with the modelling of employment. Labour demand is influenced by the economic activity in the various sectors. An increasing production level creates additional jobs. Wage rates are influenced by inflation and overall labour productivity. Increasing wages and a higher employment level accelerate the labour costs of a company and thus, may cause higher producer prices.

Figure 3 shows the economic model and the modelled interrelations at a glance. The economic model contexts are captured via identities (e. g., in the IO context; solid lines), behavioural equations that are empirically validated (dashed lines) and a few exogenously given variables (yellow marked) such as population.

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[8] Wassily Leontief was awarded the Nobel prize in Economic science in 1973 for his work on IO tables and the IO model.

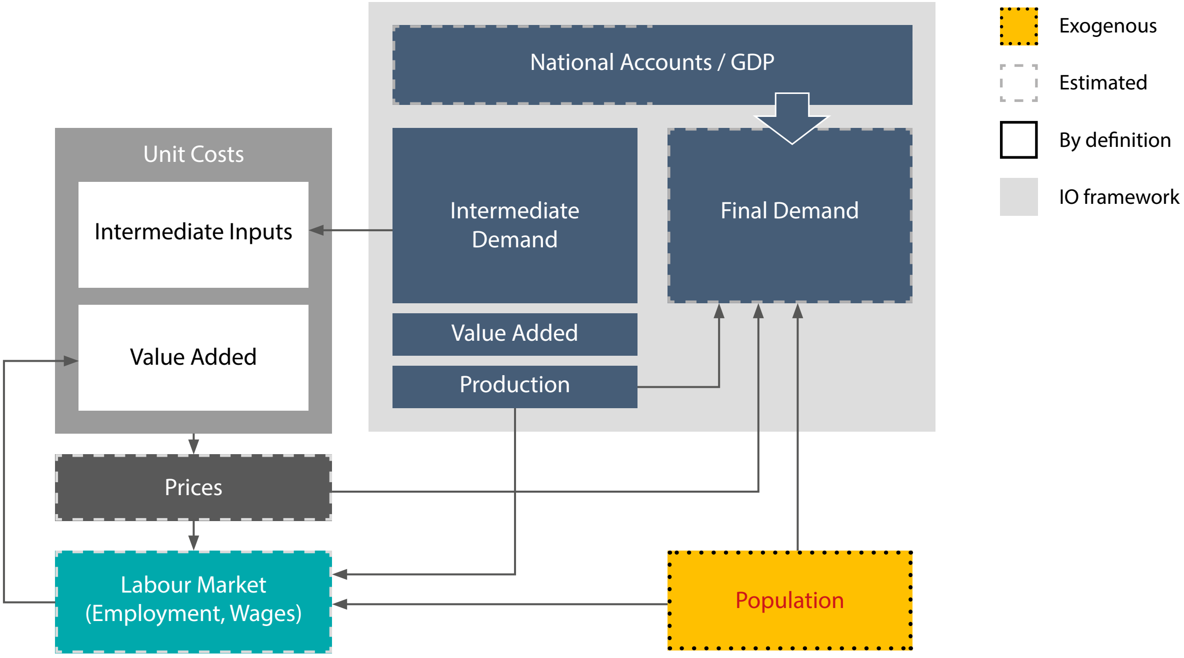


**Figure 3:** Simplified illustration of the macro-econometric IO model

Source: own representation by GWS

The presented macro-econometric Input-Output modelling approach, which covers not only quantity effects but also income and price effects, provides multipliers that determine the dynamics of the system:

- The Leontief multiplier is part of the Input-Output model and enables to calculate direct and indirect effects of demand changes (e. g., consumption, investments) on production;
- Employment and income multiplier: Increased production leads to more jobs and thus higher income resulting in higher demand (income-induced effect);
- Investment accelerator: Indicates the necessary investments to maintain the capital stock needed for production based on the demand for goods.

## ENERGY AND EMISSION MODULE

The energy and emission modules show the interrelations between economic developments, energy consumption and GHG emissions. At the core of the energy model are the energy balance, energy prices for different consumers and energy carriers. The energy balance depicts the energy demand by various economic sectors, energy conversion and energy supply for fossil fuels and renewable energy (Figure 4). The GHG emissions are connected to the primary energy use via emission factors.

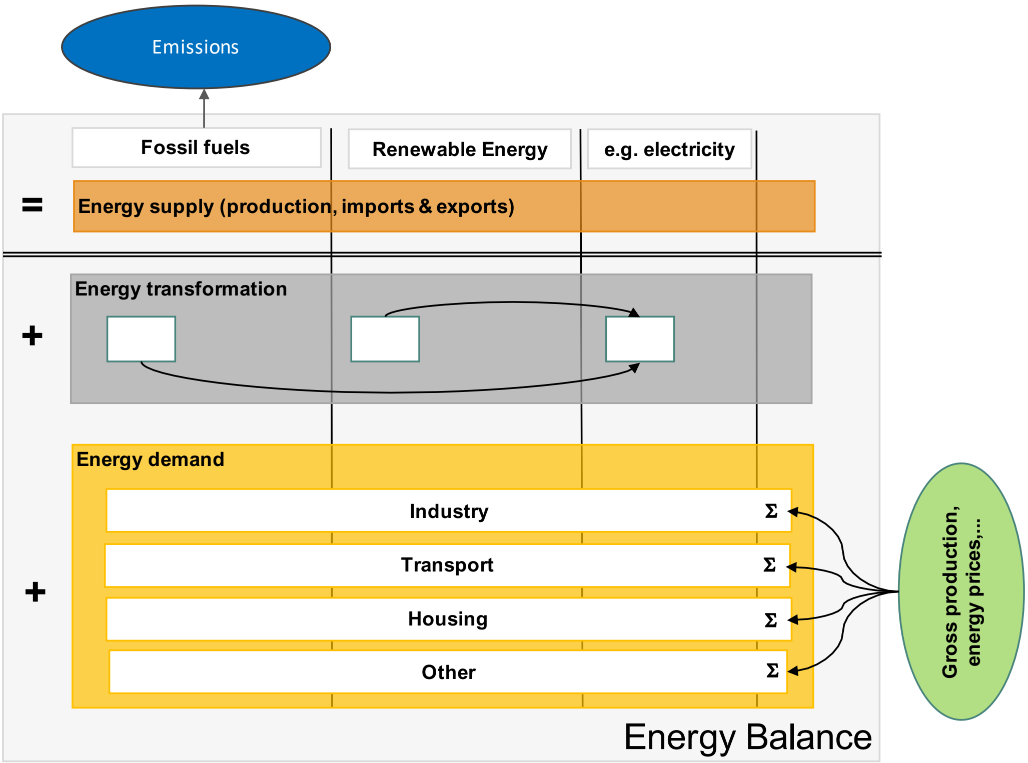


**Figure 4:** Energy module at a glance

Source: GWS

The prices of fossil fuels such as crude oil are exogenous world market prices. Energy prices to be paid for energy consumption by households and industrial consumers follow either the respective world market prices (e. g., price for oil products) or the producer price of the energy sector which reflects the cost situation in electricity generation (e. g., electricity price).

The whole energy balance is consistently modelled, and sector-specific energy demand is explained by key drivers such as sector production, population, and energy prices. Energy savings intended from energy efficiency measures reduce the energy demand. Expenditures for energy consumption have a direct influence on corresponding economic variables.

Power expansion planning and the deployment of renewable energy will be reflected in the electricity generation sector which is linked to the economic model. The installation, operation, and maintenance of renewable energy technologies are expected to show positive effects on the respective industries and its employees during various phases. However, investments in renewable energy technologies may (partly) crowd out investments in fossil fuel technologies. Possibly higher prices for electricity consumers negatively impact the household budget and result in higher energy costs for businesses.

Energy efficiency measures in the industry and residential sector are intended to save energy. This reduces energy expenditure and energy imports, which are also captured in the economic model. At the same time, demand for energy-efficient appliances and machinery is increasing.

## SCENARIOS OR “WHAT-IF” ANALYSIS

The E3 model can be used to simulate the economic effects of various energy transition scenarios planned by the Ugandan government. Scenario analysis is the methodology which economists use to deal with the uncertainties of the future. Scenarios are consistent sets of quantified assumptions describing the future development.

A scenario helps to better understand what could happen, who / what is affected and how by certain measures or policies. Thus, a scenario should not be considered a precise forecast; instead, it shows one of various possible development paths that are reactions to the specific assumptions made (“what-if” analysis).

Scenario analysis helps to analyse and quantify the impacts of “what-if” questions, e. g. “What” will happen to the economy, “if” additional capacities of renewable energy are installed, or energy efficiency is improved. Typically, such an analysis is done before a policy measure is introduced (ex-ante analysis) to explore possible reactions within the economy and likely (unwanted) impacts on the environment.

To see the effects of the policy, the policy scenario is compared to the business-as-usual scenario that does not contain the respective policy. The resulting deviations for various model variables, e. g., GDP, sectoral employment and production can be interpreted as impacts of the examined policy. Deviations for each model variable are given in % and / or absolute deviations in the underlying units e. g., monetary values or physical units (see Figure 5).

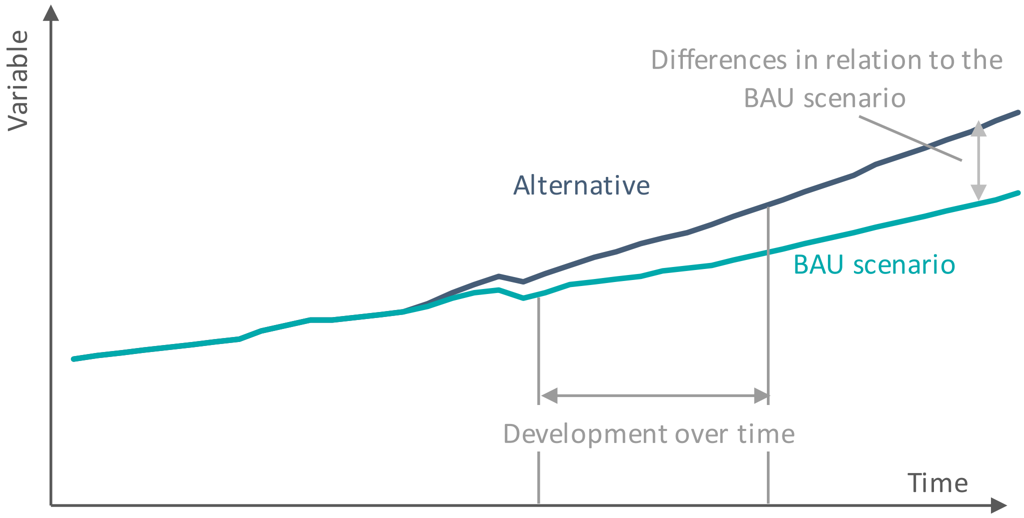


**Figure 5:** Scenario comparison

Source: own representation by GWS

In the next sections, the BAU and the policy scenarios simulated with the e3.ug model are described, and their macroeconomic results are presented. The development process and selection of the policy scenarios presented in the subsections of chapter 3 are described in section 1.4.

## DEVELOPMENT PROCESS OF THE MODEL AND THE SCENARIOS

The development process of the model and the policy scenarios was conducted as participatory approach to ensure knowledge management, capacity building as well as transparency and ownership. Meetings with relevant policy makers, data providers and local field expert took place regularly from the beginning of the project. The involvement of local experts and national modelling consultants for the modelling activities was a crucial factor for setting up the model according to the specific country needs. It also facilitated the anchorage and ownership of the model in Uganda.

An expert group was established which was part of the overall capacity building process. At the beginning, all participants were asked to share their level of knowledge and experience in modelling activities, policy advice and their preferred fields of interest. Based on the survey results and the expected time for engagement in the whole process of model building and application (scenario analysis), a group of model builders and model users was established and a training concept addressing the different training needs was developed. While model users need to know how to formulate scenario assumptions and how to evaluate scenario results, model builders must get acquainted with the main model implementation details in order to perform model updates and to implement model extensions.

The training concept was adapted to the country-specific circumstances and reflects time constraints of the participants to assure a high degree of participation. The online and onsite trainings were carried out for people from several institutions simultaneously to spread the knowledge and to facilitate mutual assistance and learning. The onsite training was conducted as a block event to support a continuous, efficient learning process for a complex topic. The first two days were dedicated to topics for model users and builders while the other two days were planned for model builders only.

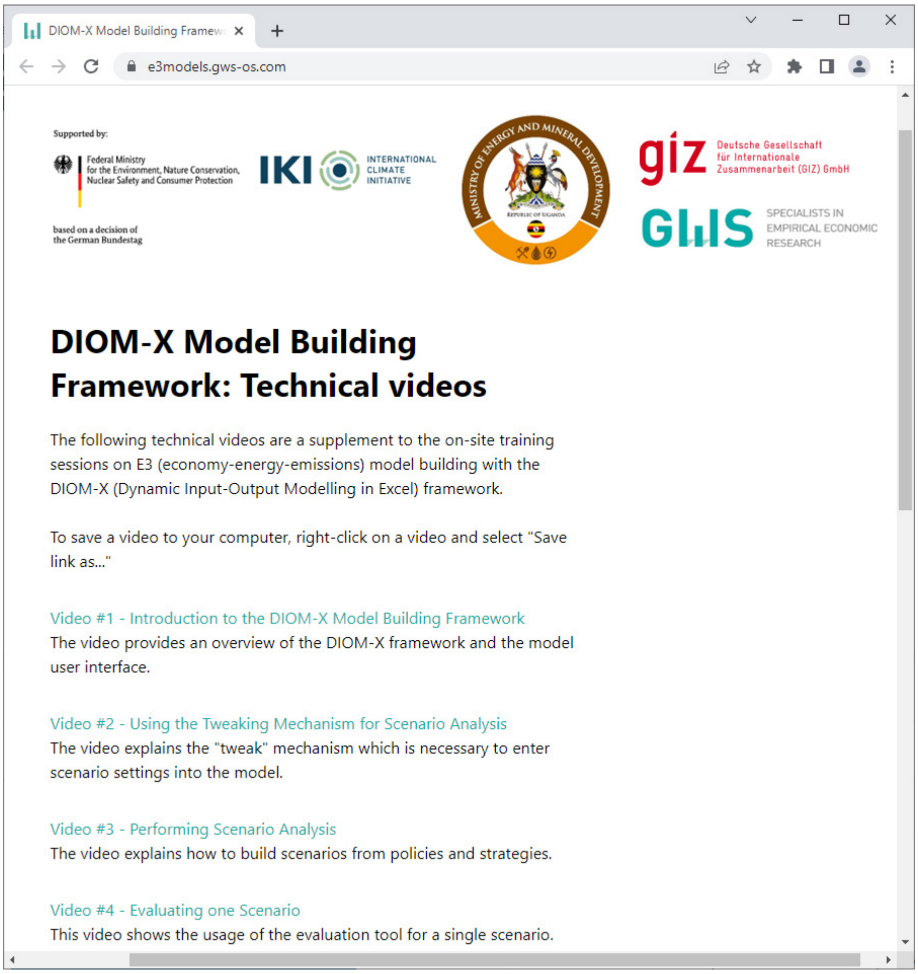
The monthly (online) expert groups meetings were dedicated to both model development and model application and experts could join the meetings according to their interest. These meetings were used to present and discuss data for building the e3.ug model, the development of the scenarios and their data needs as well as the scenario results. Furthermore, the steps of model building and the Excel-based model building framework DIOM-X were explained and accompanied by interactive exercises.

Main model building work was conducted by the international consultants. During the one-week onsite training, the e3.ug model was transferred to the training participants' computers and the data set, the E3 model parts and the results of the Excel-based e3.ug model were explained in more detail.

The training sessions for model builders and users combined introductory lessons to a specific topic and group exercises. Recap questions were asked every day to evaluate the learning progress of the participants. For exercise purposes, a stripped-down "e3ug_test" model was shared among participants which was used to conduct a sequence of basic exercises.

Due to the highly interactive, lively discussions and the high interest to learn more than what was initially scheduled, the training was extended by one more day dealing with topics in particular interesting for model builders.

Learning materials such as PowerPoint presentations, the e3.ug model handbook and nine training videos preserve the knowledge in a condensed form. These are accessible for the training participants at the website https://e3models.gws-os.com/ (see Figure 6).



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DIOM-X Model Building Framework: Technical videos

The following technical videos are a supplement to the on-site training sessions on E3 (economy-energy-emissions) model building with the DIOM-X (Dynamic Input-Output Modelling in Excel) framework.

To save a video to your computer, right-click on a video and select "Save link as..."

Video #1 - Introduction to the DIOM-X Model Building Framework
The video provides an overview of the DIOM-X framework and the model user interface.

Video #2 - Using the Tweaking Mechanism for Scenario Analysis
The video explains the "tweak" mechanism which is necessary to enter scenario settings into the model.

Video #3 - Performing Scenario Analysis
The video explains how to build scenarios from policies and strategies.

Video #4 - Evaluating one Scenario
This video shows the usage of the evaluation tool for a single scenario.

**Figure 6:** Screenshot from the e3models.gws-os.com website

Source: https://e3models.gws-os.com/

The aim of the introductory, technical videos is to recap certain steps to build and to use the model as discussed during the training sessions:

1. General introduction to the DIOM-X model building framework
2. How to tweak model variables?
3. How to perform scenario analysis?
4. How to evaluate results of one scenario?
5. How to compare and evaluate results of two scenarios?
6. How to add a new model variable?
7. How to update historical data for an existing model variable?
8. How to modify regressions?
9. How to edit the (VBA) model code?

The first five videos are relevant for the model users and model builders. The videos number six to nine are in particular relevant for model builders.
The e3.ug manual contains additional information on how the e3.ug model was built using DIOM-X which is not to be found in the videos (Großmann et al. 2022).

The scenarios presented in chapters 2 and 3 are the result of the collaboration between the policy partners (e. g., MEMD, MoFPED), country experts, GIZ, and the international consultants during the project period. The aim was to identify key policy questions, to discuss future energy policy strategies and map these strategies into possible scenarios (see Figure 7). Information, studies, and data were shared that informed the scenario development process.

The selected policies and measures were combined into two „energy transition" scenarios. The first policy scenario „Expansion of renewable energy and electricity access" includes the expansion of grid access both on and off grid, the expansion of renewable electricity generation from solar PV and hydro power, and the increased use of electricity by households. The second policy scenario „Improving the energy efficiency" includes energy efficiency measures in industry, commerce, residential and the energy sector.

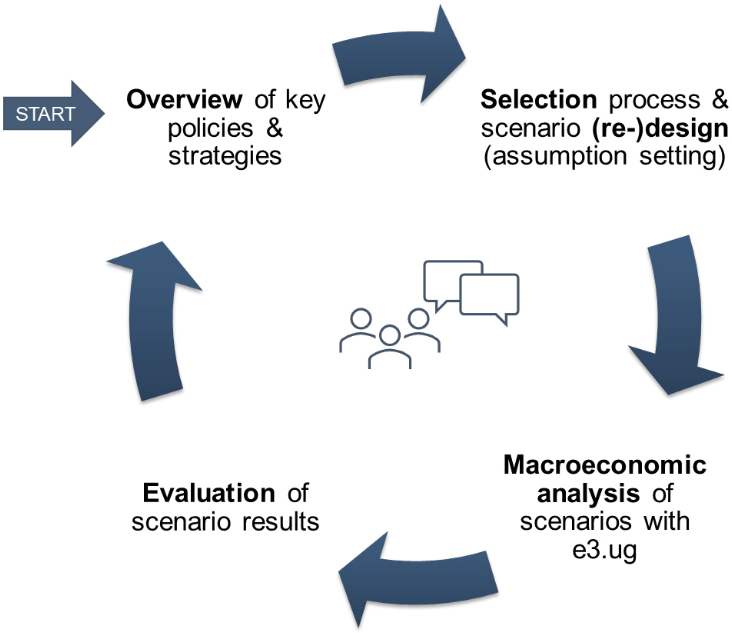

**Figure 7:** Scenario development process
Source: GWS

The scenario assumptions and scenario results were discussed with the expert group online and with policy-makers, statisticians and field experts during the one-week onsite training. One outcome was the adjustment of the business-as-usual scenario. Among others, it was decided that the expansion of electricity access should be part of the business-as-usual scenario and that the UBOS population projections should replace those of the UN.

Furthermore, modifications in the policy scenarios were decided and implemented in order to take into account current and future energy policy plans (NDCs, LTS; e. g., (MEMD 2021, 2022a, 2022b; La Rue Can et al. 2017; Harries et al. 2021):

- Additional renewable energy technologies have been included in the model and scenarios, e. g., wind, and geothermal energy
- Adjustment of assumptions for clean cooking according to updated energy policy
- Adjustment of assumptions for the use of efficient cooking technologies according to updated energy policy

The updated and new scenarios were calculated and evaluated both separately and in a combined „Current energy policy planning" scenario (section 3.2.1–3.2.4). National modelling consultants that are involved in the participatory approach will build on these scenarios and create, calculate, and evaluate further policy scenarios.

The training experiences have shown once again that learning a complex and multi-layered topic such as model building is not completely possible within a limited time frame. The training sessions serve as a starting point to get a basic understanding how an E3 model works and how it can be applied to create, simulate, and evaluate scenarios (model application).

Further trainings should be conducted to deepen the understanding and to further explore how the model can be updated and extended to answer also other policy questions (see section 4.1).

However, the e3.ug model which uses the Excel-based DIOM-X framework in conjunction with intensive capacity building reduces the typical technical hurdles of model building and application tremendously. The "white box" approach not only ensures that each and every aspect of the model (data, model code and equations, results) is accessible and customizable but also increases confidence and the awareness of possible applications as well as limits of the model. Transferring full ownership of the model to the country partners allows for evaluating and for continuous monitoring of the energy transition.

However, the successful development and integration of the e3.ug model into strategic planning processes is linked to various preconditions.

For a data-driven model such as e3.ug, the quality of results greatly depends on the quality and timely availability of the underlying historic data. However, the requirements for data and model approach are kept moderate for a sustainable solution. The goal was to develop a tool that is understandable for model builders and users, and suitable for the key questions to be investigated.

A critical success factor for building capacities is related to the availability of local project partners and continuous participation in the model building and application process. Another aspect is brain-drain which can be caused by project members leaving the partner institutions.

# 2 BUSINESS-AS-USUAL SCENARIO

## ASSUMPTIONS

The business-as-usual scenario extrapolates the relationships observed in the past into the future. Model variables, model parameters and assumptions are carefully selected to provide a reliable baseline projection and to provide a solid basis for other scenario analyses. The economic development is mainly driven by population, expectations about world market developments and endogenous growth as it has been evolved in the past.

The business-as-usual scenario is not to be interpreted as a projection in terms of the most realistic development. It serves as a benchmark to compare model results of policy scenarios. Nevertheless, the BAU projection should meet certain expectations.

Population growth will continue until 2050, although at a reduced speed. According to the national population projections for Uganda from the Uganda Bureau of Statistics (UBOS), growth rates will slow down from about 3.1% per year of the last decade from 2010 to 2020 to an average of 2.9% (2020–2030) and 2.3% (2030–2040) per year in the following decades, slowing down further afterwards averaging 1.9% per year in the years 2040 to 2050. Population is expected to be more than twice as high in 2050 than it was in 2020 (see Figure 8).

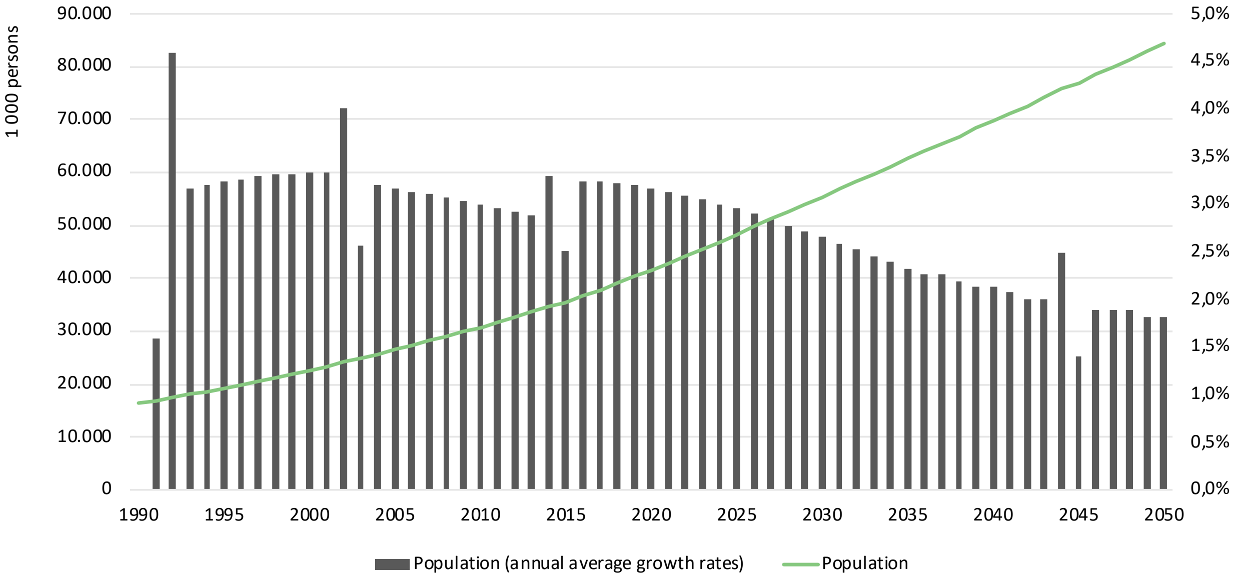

**Figure 8:** Business-as-usual scenario: Population development in 1,000 persons and average annual growth rate in % (1990–2050)

Source: UBOS (2022d)

Nominal exports follow the International Monetary Fund (IMF) projection for Uganda until 2030 which is expected to increase from 7.2 Bn. USD in 2022 to 14 Bn. USD in 2030 (IMF 2022). Afterwards exports are expected to increase at an average growth rate of 5% p.a. as in the past.

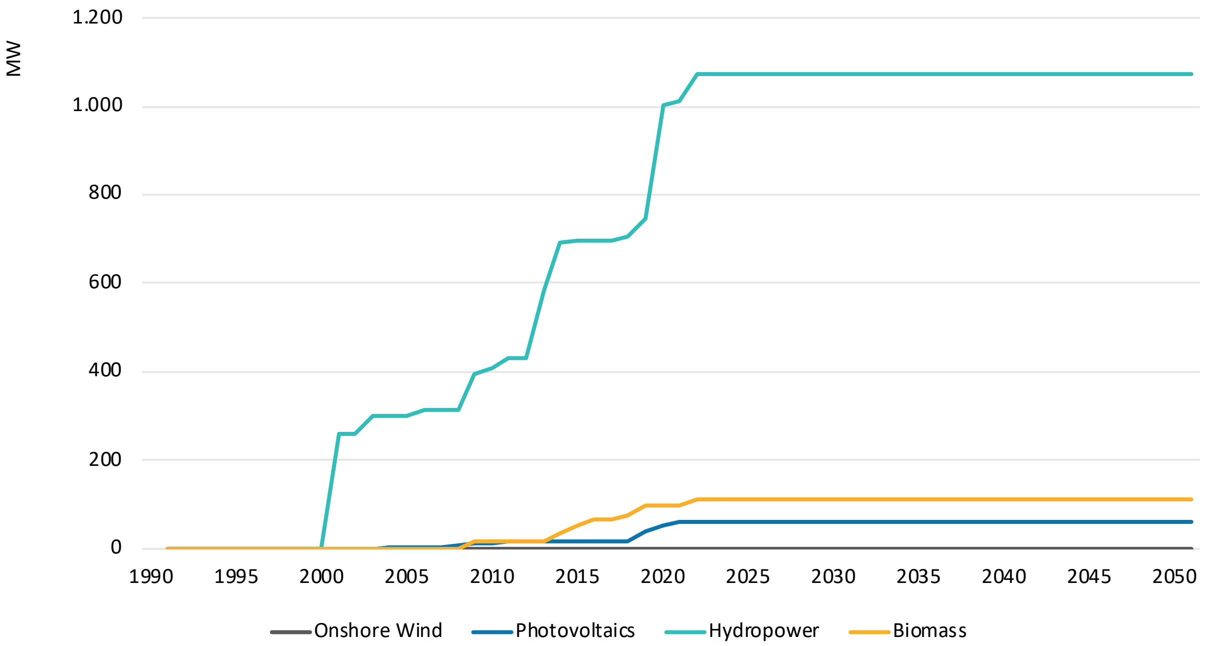

**Figure 9:** Business-as-usual scenario: Renewable energy capacity in MW (1990–2050)

Sources: ERA (2022), IRENA (2021a)

World market price indices for traded commodities such as basic metals, agricultural products and fertilizers follow the projections of the World Bank and IMF until 2024 and 2027 respectively. These projections cover the impacts of Russia's war in Ukraine. Afterwards, the price indices follow their historical trend. The crude oil forecast is taken from the stated policy scenario of the IEA World Energy Outlook (IEA 2021, p. 101) until 2050.

In all scenarios price increases for crude oil, fertilizers and wool are assumed to be over 5% per year in the next decade, with metals averaging slightly below. Price increases for various agricultural products lie in the range of 2–4% per year. In the time frame 2030 to 2050, price indices are then assumed to increase at a lower rate between 0.5% and 2% per year (World Bank 2022a).

For the energy sector, no energy transition is foreseen in the business-as-usual scenario. The installed capacity of renewable energy systems will remain at its current level. In 2021, the installed capacity of photovoltaics is 61 MW, hydropower is at 1,072 MW and biomass amounts to 112 MW while wind power remains non-existent (see Figure 9).

The number of electricity connections is assumed to increase in the business-as-usual scenario according to the business-as-usual scenario in Uganda's long-term climate change strategy (Harries et al. 2021). In 2021, four million households – which is 58% of all households – have access to electricity. By 2040 all households will have the opportunity to use electricity (see Figure 10). The associated costs for the on- and off-grid connections range between 76 USD (stand-alone solar systems) and 1,519 USD (solar mini grids) per type of electricity connection (MEMD 2021).

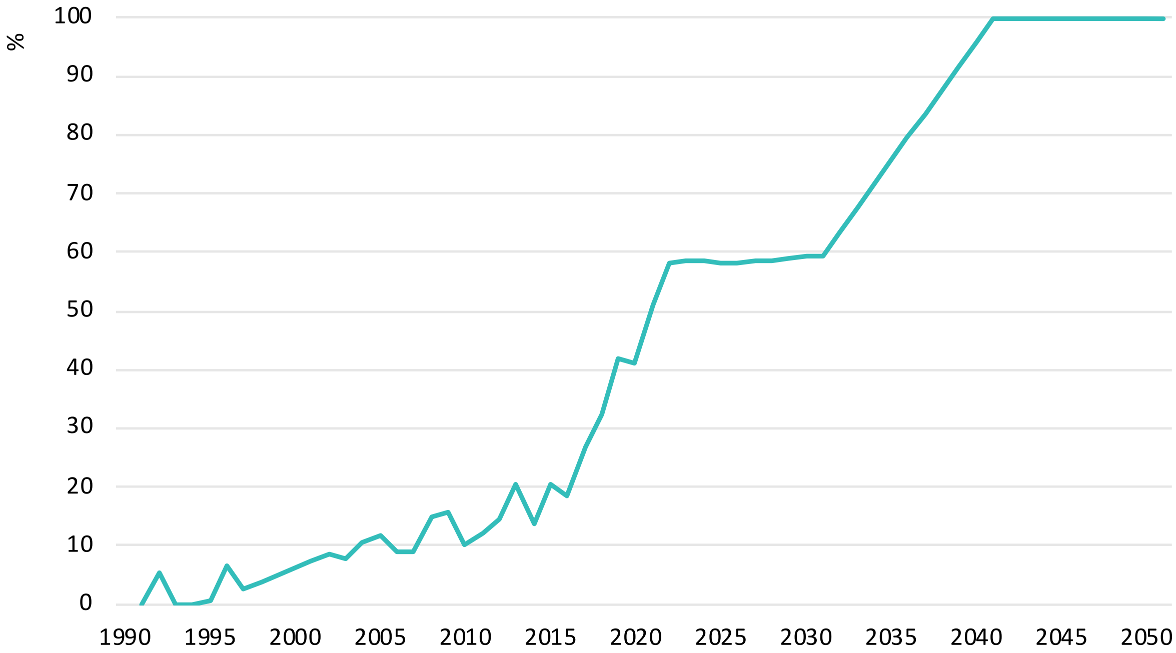

**Figure 10:** Business-as-usual scenario: Access to electricity in % of population (1990–2050)

Sources: World Bank (2022b), MEMD (2022a), projections adopted from Harries et al. (2021)

Following Harries et al. (2021), the fuel mix is assumed to remain unchanged for the projection period until 2050, except for Liquefied Petroleum Gas (LPG) and the sectors shown in Table 1 which provides the target values for the years specified.

| Sector | 2025 | 2030 | 2050 |
|---|---|---|---|
| Industry | 8% |  | 12% |
| Commerce, institutions |  | 15% |  |
| Residential | 8% | 10% | 10% |

**Table 1:** Business-as-usual scenario: Share of LPG by sector in % (2025, 2030, 2050)

Source: Harries et al. (2021)

With an increasing share of households having access to electricity, the fuel mix will change. However, without increasing income and penetration of electrical appliances, electricity demand per household will not change significantly.

No further improvements of energy efficiency in the industrial and commercial/institutional sectors as well as charcoal production is assumed. For the residential sector, an ongoing deployment of 65,000 improved cookstoves (ICS) p.a. is expected.

# RESULTS

## ECONOMIC DEVELOPMENT

In the business-as-usual scenario the Ugandan economy is expected to continue to grow until 2050, but at a slower rate. In the first projection period the average annual growth is 4.9% (2020–2030), followed by 4.1% 2030–2040 and 3.5% (2040–2050, see Table 2). In 2050, GDP will be 429 Tn. UGX, which is more than three times higher than in 2020 (126 Tn. UGX).

Economic growth is mainly driven by domestic demand and also influenced by a decelerated population growth rate by 2050. Export growth is assumed to be at a lower growth path (IMF 2022).

The largest contribution to growth stems from private household consumption, followed by gross fixed capital formation (see Figure 11). However, growth rates of gross fixed capital formation exceed those of GDP and consumption expenditures of households and non-profit institutions serving households (NPISH, see Table 2).

| Average annual growth rates | 2000–2010 | 2010–2020 | 2020–2030 | 2030–2040 | 2040–2050 |
|---|---|---|---|---|---|
| GDP | 7.8% | 5.1% | 4.9% | 4.1% | 3.5% |
| Consumption expenditures of households & NPISH | 6.7% | 4.6% | 5.1% | 4.2% | 3.4% |
| Consumption expenditures of government | 5.6% | 7.4% | 5.1% | 4.0% | 3.3% |
| Gross fixed capital formation | 9.9% | 5.6% | 5.6% | 5.0% | 4.1% |
| Exports | 5.3% | 6.8% | 6.7% | 3.6% | 3.7% |
| Imports | 9.6% | 3.6% | 8.2% | 5.1% | 4.2% |

**Table 2:** Business-as-usual scenario: Real GDP and components, average annual 10-year growth rates in % (2000–2050)

Sources: UBOS (2022d), e3.ug results (2022–2050)

Government consumption expenditures follow population growth and thus slowdown in the projection period.

Due to the strong import dependency, in particular in the manufacturing sector, imports are expected to further increase.

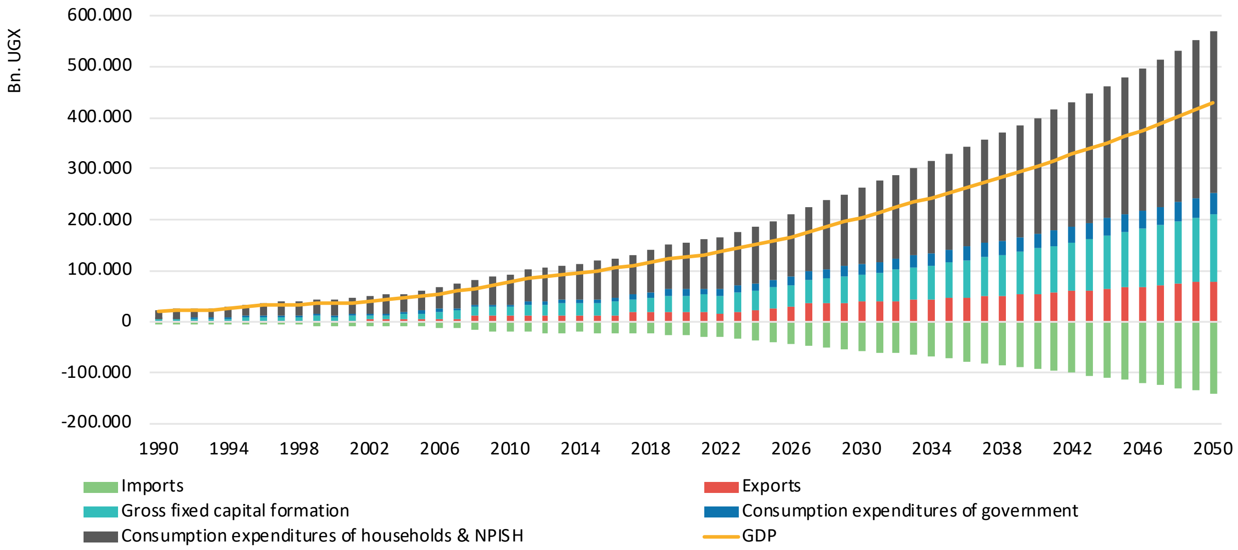

**Figure 11:** Business-as-usual scenario: Real GDP and components in Bn. UGX (1990–2050)

Sources: UBOS (2022d), World Bank (2022b), e3.ug results (2022–2050)
To account for the decomposition approach of the GDP, imports are depicted as negative values.

The import deflator – which measures the import price development – is expected to increase until the end of simulation period at a slower rate (ranging between 1.2% and 1.9% p.a.) than in the historical period (see Table 3). As mentioned in section 2.1, in the first projection period it follows projections from the World Bank and IMF, afterwards the import price indices follow their historical trend. The strong price increase of e. g., fertilizers and crude oil especially in 2022 due to the war in Ukraine, is considered in the projection. The average wage rate is further increasing. During the decade 2020–2030, the average wage rate is accelerating following the high inflation. In the subsequent decades, growth rates are declining to 3.8% p.a. (see Table 3).

The GDP deflator evolves in line with the average wage rate and the import deflator resulting in a growth rate averaging 2.9% p.a. over the 2040–2050 period.

| | 2000–2010 | 2010–2020 | 2020–2030 | 2030–2040 | 2040–2050 |
|---|---|---|---|---|---|
| GDP Deflator | 10.6% | 4.7% | 5.1% | 4.0% | 2.9% |
| Average wage rate | – | 6.0% | 6.9% | 5.4% | 3.8% |
| Import deflator | 9.8% | 4.8% | 1.9% | 1.4% | 1.2% |

**Table 3:** Business-as-usual scenario: Wage and price developments, average annual 10-year growth rates in % (2000–2050)

Sources: UBOS (2022d), World Bank (2022b), e3.ug results (2022–2050)

Sectoral production follows the macroeconomic development considering inter-industry relationships. Export-oriented sectors generally show a stronger connection to foreign demand. Consumption-oriented sectors are more dependent on domestic demand. No structural changes of the economy or economic diversification are assumed. Figure 12 shows the results for real gross output by economic sectors.

Real gross output increases from 188 Tn. UGX in 2020 to 785 Tn. UGX in 2050. As in the past, the service sector (37% by 2050) and manufacturing sector (23% by 2050) contributing the most to real gross output, followed by “agriculture, forestry and fishing” (18% by 2050) and “trade and transport” (10% by 2050).

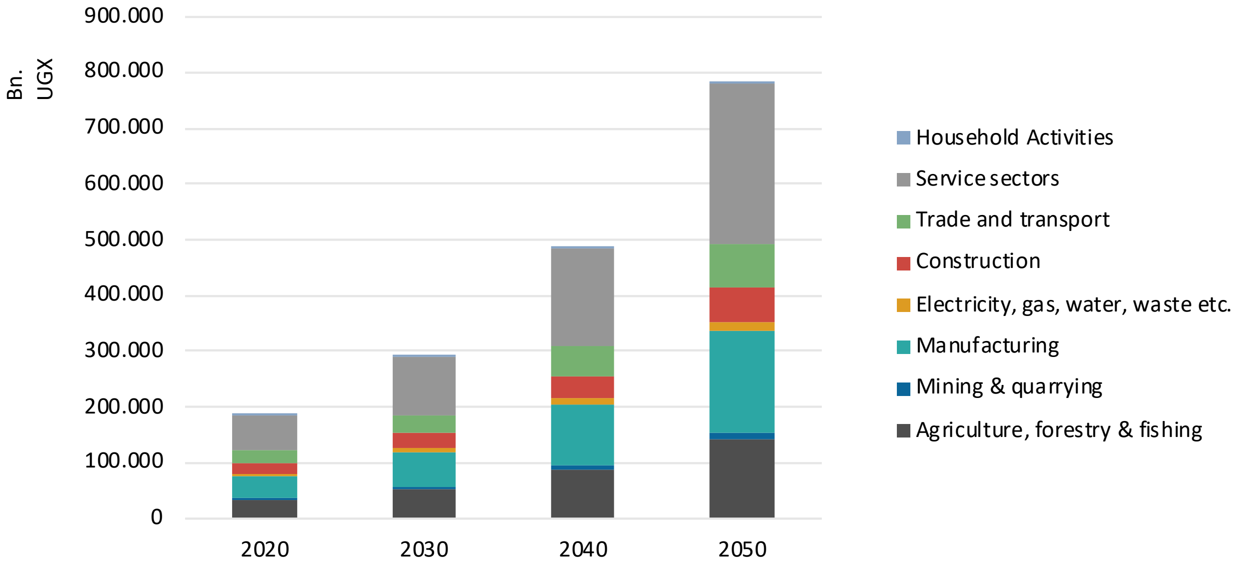

**Figure 12:** Business-as-usual scenario: Real gross output by economic sectors in Bn. UGX (2020, 2030, 2040, 2050)

Source: e3.ug results

Population at working age and labour force are growing steadily (see Figure 13). Sectoral employment follows sectoral production resulting in almost 40 Mn. employed persons by 2050 (see Figure 14).

By far, the majority of employed persons work in the agricultural sector which is 12 Mn. persons resp. 73% of all employed persons in 2020 increasing to 30 Mn. Persons by 2050. The trade and transport sector as well as the service sector account for approx. four million jobs each by 2050. Employment in other sectors remain limited due to lower production levels and higher labour productivity.

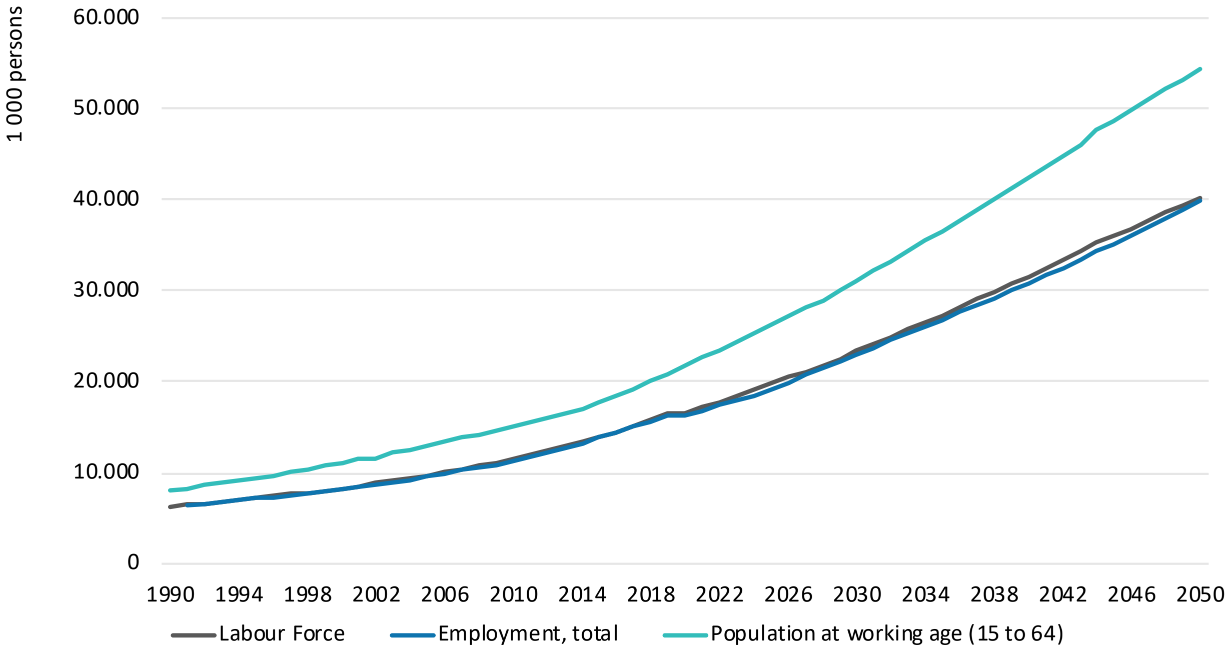

**Figure 13:** Business-as-usual scenario: Labour market indicators in 1,000 persons (1990–2050)

Sources: ILO (2022a), ILO (2022b), World Bank (2022b), e3.ug results (2022–2050)

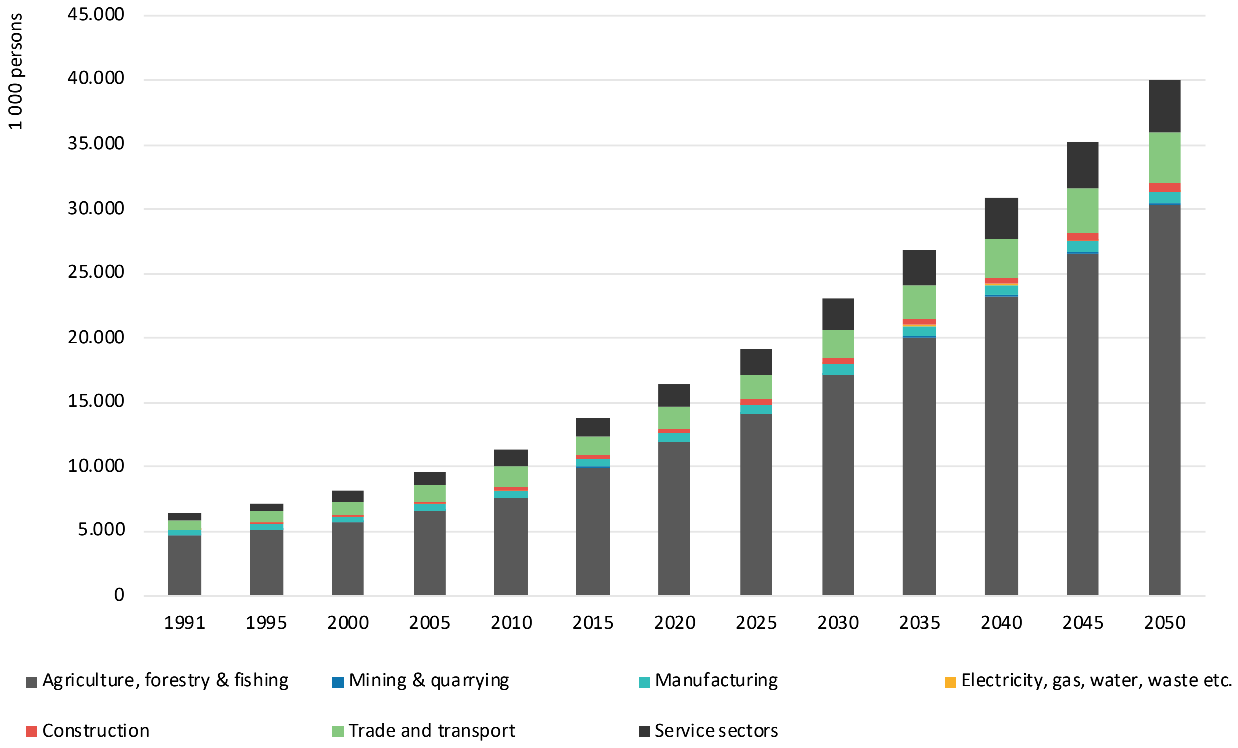

**Figure 14:** Business-as-usual scenario: Employment by economic activities in 1,000 persons (1991–2050)

Sources: ILO (2022a), ILO (2022b), e3.ug results (2022–2050)

## ENERGY AND EMISSIONS

Energy prices follow the world market price projections for crude oil and wood. After a strong increase in 2021 and 2022, the upward trend in prices is easing which results in a slowdown for oil products and charcoal in the subsequent periods (see Table 4). Electricity prices for various consumer groups will decelerate as well.

| Energy prices by fuels | 2000–2010 | 2010–2020 | 2020–2030 | 2030–2040 | 2040–2050 |
|---|---|---|---|---|---|
| Average weighted retail prices of pretroleum products (UGX per liter) | 10.8% | 3.4% | 1.6% | 0.7% | 0.6% |
| Average market price for charcoal (UGX per kg) | 9.4% | 10.2% | 1.6% | 1.1% | 1.0% |
| Average weighted domestic electricity tariffs (UGX per kWh) | 3.7% | 11.8% | 5.8% | 3.4% | 2.3% |
| Average weighted commercial electricity tariffs (UGX per kWh) | 2.2% | 12.5% | 5.6% | 3.4% | 2.3% |
| Average weighted large industrial electricity tariffs (UGX per kWh) | 1.5% | 7.5% | 5.9% | 3.6% | 2.4% |

**Table 4:** Business-as-usual scenario: Energy prices by fuels, average annual 10-year growth rates in % (2000–2050)

Sources: UBOS (2022a), UBOS (2022c), UBOS (2022b). e3.ug results (2022–2050)

Total final energy consumption (TFEC) is mainly driven by the residential sector whose demand more than triples from approximately 9,400 ktoe in 2020 to almost 33,000 ktoe within 30 years (see Figure 15). Population and income growth are the key drivers of this development.

Total final energy consumption of other sectors is mainly driven by their economic activity. In the industry sector total final energy consumption nearly triples resulting in 9,500 ktoe by 2050; in the transport sector it is 6,700 ktoe by 2050.

Biomass and waste are the main fuels, although their share declines from 85% in 2020 to 78.5% in 2050 (see Figure 15). This is mainly due to the use of more oil products, in particular LPG being expected to increase in the BAU (from approx. 2,000 ktoe in 2020 to approx. 11,000 ktoe in 2050). The use of electricity remains low.

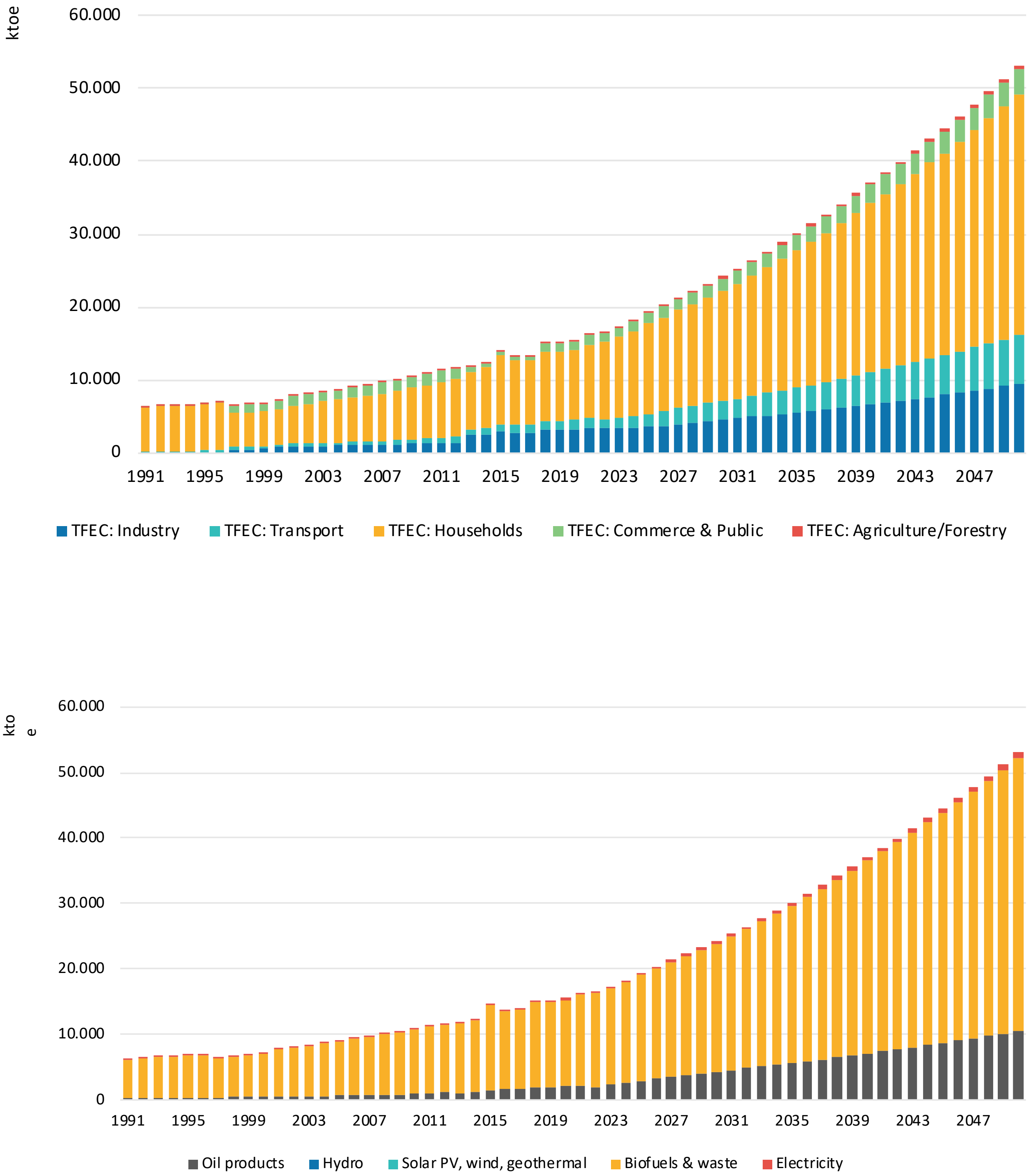

**Figure 15:** Business-as-usual scenario: Total final energy consumption by sector (top figure) and by energy carriers (bottom figure) in ktoe (1991–2050)

Sources: UN (2022), e3.ug results (2020–2050)

Greenhouse gas (GHG) emissions increase further to 267,340 Gg $CO_2$ equivalents in 2050 (see Figure 16). Sectors consuming oil products and biomass, such as the residential, transport and industry sector, contribute to this development. However, carbon dioxide emissions from biomass sources are accounted for in the forest land sector and not in the energy, transport, industry, or other sectors. These sectors only cover Greenhouse gas (GHG) emissions other than $CO_2$.

Thus, emissions from forest land are most significant, followed by emissions from the transport and industrial sectors which also use oil products.

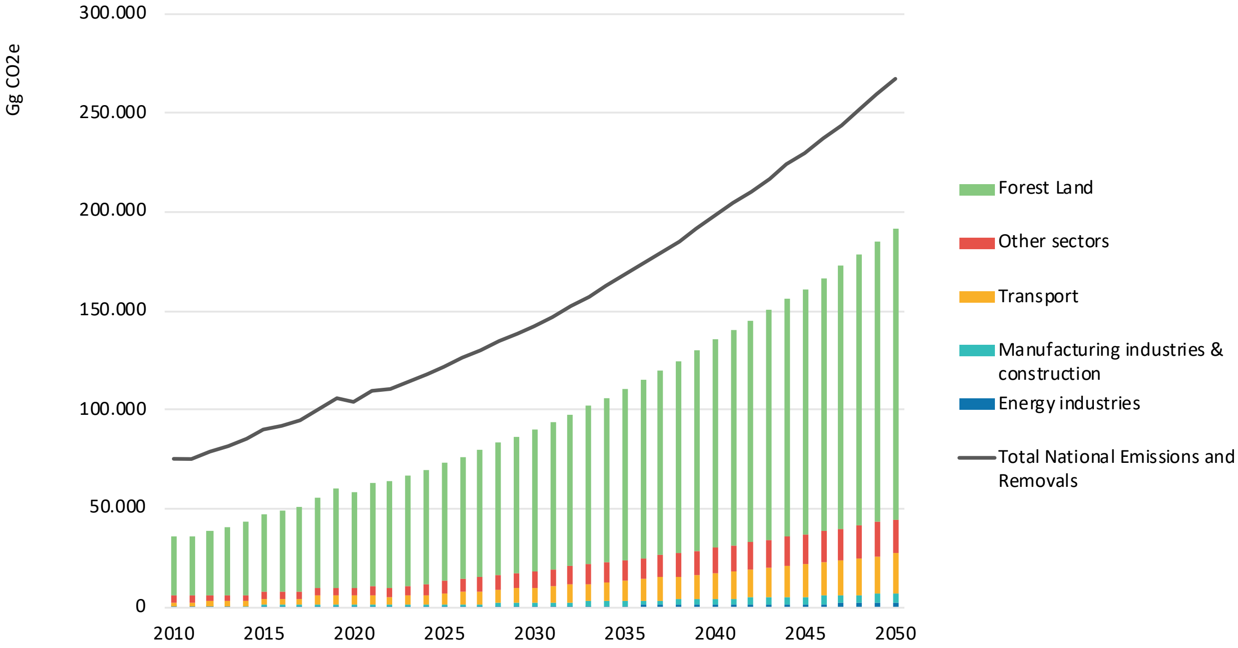

**Figure 16:** Business-as-usual scenario: GHG emissions by sectors in Gg $CO_2$ equivalents (2010–2050)

Sources: MWE (n. d.), e3.ug results (2018–2050)
The difference between "total national emissions and removals" and the sum over all sectors mentioned in the legend covers all sector contributing to GHG emissions but are not explicitly modelled with e3.ug.

As depicted in Figure 17, most emissions occur as $CO_2$ emissions to which the transport, manufacturing, and construction sectors contribute the most. $CH_4$ and $N_2O$ emissions are mainly emitted from the agriculture sector (livestock and managed soils) and to a lesser extent also from the waste sector[9]. Fuel combustion activities contribute to $CH_4$ and $N_2O$ emissions to an even lesser extent (MWE (n. d.))[10].

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[9] GHG emissions from the agriculture and waste sectors are not covered in the e3.ug model.

[10] Fuel combustion-related emissions from agriculture are covered in „other sectors". Emissions from livestock, cropland and managed soils not.

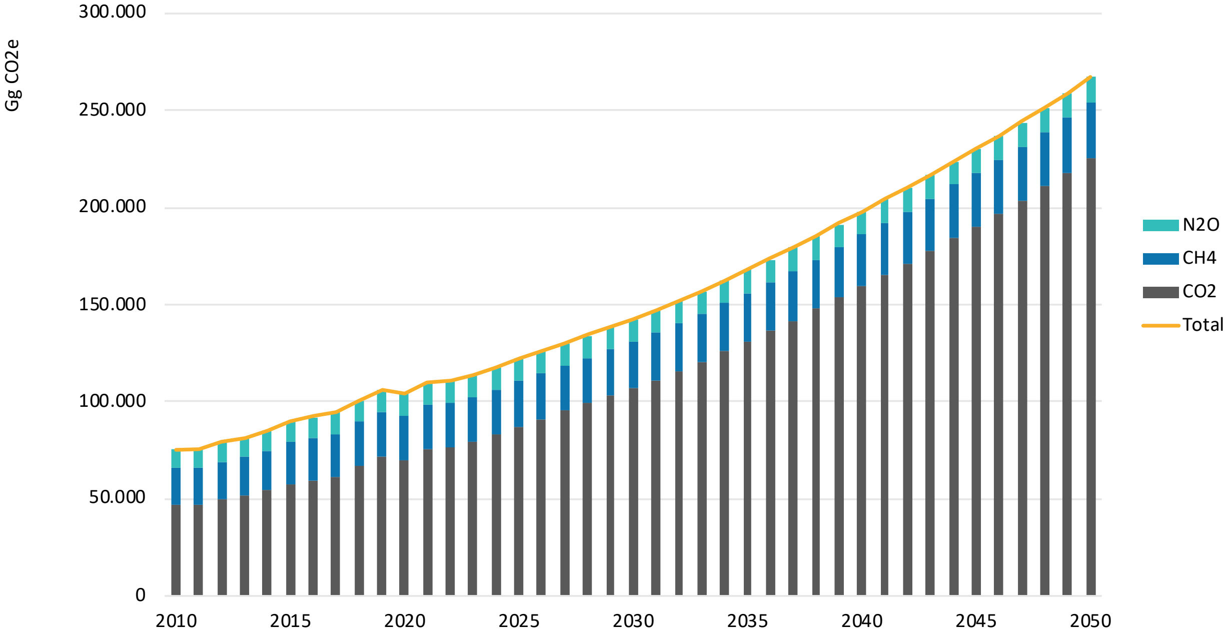

**Figure 17:** Business-as-usual scenario: GHG emissions by type of gas in Gg $CO_2$ equivalents (2010–2050)

Sources: MWE (n. d.), e3.ug results (2018–2050)

# 3 ENERGY TRANSITION SCENARIOS

## SCENARIO DESCRIPTION AND SETTINGS

The following scenarios analyse the macroeconomic impacts of Uganda's planned energy transition which reflects the current energy policy planning (CEPP) in Uganda comprising further renewable energy development until 2040, energy efficiency improvements and an increased access to clean cooking technologies in Uganda until 2030. The access to electricity is accelerated. Almost six million additional households will be connected to the grid by 2030 which is ten years earlier than planned in the business as usual scenario (MEMD 2022a).

The total renewable energy **installation** of 4,574 MW will be reached in 2040 following Uganda's Energy Policy Plan 2022 (MEMD 2022b). Most of the additional capacity is installed by 2030 with hydropower[11] (1,658 MW) providing the largest contribution, followed by geothermal (183 MW), solar PV (144 MW), biomass (72 MW) and wind (20 MW), see Table 5). An additional hydropower capacity of 1,252 MW is planned by 2040. The new installations follow a steady development path.

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[11] Planned hydro power projects are for example Karuma, Kiba, Oriang, and Agago (MEMD 2022b).

| RE technology | Additional installed capacity by 2022–2030 [MW] | Additional installed capacity by 2031–2040 [MW] |
|---|---|---|
| Hydro | 1,658 | 1,252 |
| Solar PV | 144 | |
| Wind | 20 | |
| Geothermal | 183 | |
| Biomass | 72 | |
| TOTAL | 2,077 | 1,252 |

**Table 5:** Contribution of new renewable energy projects to Uganda's electricity mix by 2030 / 2040

Source: MEMD (2022b)

Average investment costs per kilowatt (kW) for manufacturing and installation (M&I) by technology are taken from MEMD (2022b) or in the case of wind from IRENA (2021b). The investment costs range from 1,660 USD/kW for wind to 4,440 USD/kW for geothermal.

Operation and maintenance (O&M) costs by technology are based on statistics from Electricity Regulatory Authority (ERA) except for wind and geothermal which are taken from the Timilsina (2020). Operation and maintenance costs expressed in percent of manufacturing and investment costs range from 2.1% for hydro and 4.5% for solar PV.

| RE technology | Manufacturing and installation costs [USD/kW] | Operation and maintenance costs [in % of M&I] |
|---|---|---|
| Hydro | 1,950 | 2.1 |
| Solar PV | 1,410 | 4.5 |
| Wind | 1,660 | 2.6 |
| Geothermal | 4,440 | 4.0 |
| Biomass | 4,060 | 2.3 |

**Table 6:** Manufacturing and investment costs per kW in USD and operation and maintenance costs in % of manufacturing and investment

Sources: IRENA (2021b), MEMD (2022b), Timilsina (2020)

Another policy measure are EE improvements which are considered for the residential, commercial, and industrial sector as well as for the energy sector. The anticipated savings in electricity for the residential, commercial, and the industrial sector are taken from the Energy Efficiency Roadmap for Uganda which focusses only on electrical energy efficiency. According to this, between 14% to 16% of the electricity can be saved (medium variant) which comes at costs as specified in Table 7. The incremental costs per average annual savings range from 0.01 USD / kWh to almost 2 USD / kWh.

| Sectors | Achievable economic potential | | | |
|---|---|---|---|---|
| | **Medium** | Low | High | Incremental cost per average annual savings (in USD / kWh) |
| Residential | **14%** | 11% | 16% | 0.1 – 1.58 |
| Commercial | **14%** | 10% | 23% | 0.04 – 1.95 |
| Industrial | **16%** | 8% | 24% | 0.01 – 0.88 |

**Table 7:** Electricity savings in % and incremental cost per average annual savings in USD / kWh

Source: La Rue Can et al. (2017)

The potential for preventing network losses is taken from the grid development plan of Uganda Electricity Transmission Company Limited (UETCL 2020, p. 22) assuming a further reduction of transmission and distribution losses to 15.3% until 2030. The associated investments are derived from the IEA (2019) study and account for 27 Bn. UGX.

EE in the residential sector can be also improved by moving away from the three-stone fire or artisanal to industrial cookstoves which are more efficient but are still using wood or charcoal. Fuel savings of 35% to 50% are achievable (First Climate 2020). More efficient cooking technologies are expected to be used by 10% of private households (which corresponds to 1.2 million households) and by 10% of institutions (4,000) by 2025 (MEMD 2022a, MWE 2022, p. 19).

Firewood and charcoal use for cooking can also be reduced by improved access to clean cooking technologies such as LPG and electrical cookstoves. According to MEMD (2022a), the number of households using clean energy increases to 40% by 2030. 30% will be using LPG and 10% will be using electricity for cooking which amounts to 1.4 million households.

Ugandan government subsidizes the upfront costs of clean cookstoves with 8 Bn. UGX until 2030 (MEMD 2022a, p. 87) and since 2022 provides a reduced electricity tariff (cooking tariff[12]) to make the use of electricity more affordable. However, it is expected that even households equipped with electric cookstoves will continue to use their traditional cookstoves at 50%. In a separate sensitivity analysis it is assumed that households will completely use the electric cookstove to analyse these impacts as well.

In the following section, the macroeconomic results for the three subscenarios “RE expansion”, “EE improvements” and “Clean cooking” are presented separately. Afterwards, all subscenarios are combined into a “CEPP” scenario and illustrated thereafter.

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[12] https://www.era.go.ug/index.php/media-centre/what-s-new/371-energy-minister-launches-reviewed-electricity-tariff-struc-ture#:~:text=The%20Cooking%20Tariff%20is%20a,cooking%20using%20charcoal%20in%20homes (last accessed August 19th, 2022)

# RESULTS

## SUBSCENARIO 1: “RENEWABLE ENERGY EXPANSION”

The expansion of renewable energy has positive impacts on GDP and employment. Investments in additional renewable energy capacity support GDP growth during manufacturing and investment as well as operation and maintenance. The impacts on GDP and its components are shown in Figure 18.

GDP increases by up to 0.5% per year compared to the business-as-usual scenario. Main drivers are the initial investments in renewable energy which sum up to approximately 25,000 Bn. UGX over the whole simulation period. By 2030, investments have a larger impact than in the subsequent period, as biomass and geothermal have high investment costs per installed capacity compared to hydropower which is the only renewable energy technology that continues to expand until 2040. Investments increase up to 1.9% p.a. compared to the business-as-usual scenario.

**Figure 18:** Real GDP and components (deviations from business-as-usual scenario in %, 2022–2040)

Source: e3.ug results

Products and services for renewable energy investments are partly imported which curtails GDP growth. For example, electrical equipment (66%), machinery (79%), metal products (49%) and engineering services (49%) are imported. But increasing renewable electricity generating capacities replace oil products and biomass, which reduces respective imports. Overall, imports are up to 0.8% p.a. higher than in the business-as-usual scenario.

Government consumption is up to 0.3% below the business-as-usual scenario. Investment costs are partly financed by the government and are expected to crowd out other government consumption spending.

The increase in domestic production induces additional jobs which increases households’ income and allows for additional consumption expenditures of additional 0.4% in 2030 compared to the business-as-usual scenario.

The macroeconomic development is also reflected in the production by economic sectors. The construction and manufacturing sectors benefit from higher demand for construction services to build the renewable energy plants (see Figure 19). In particular, manufactured products such as electrical equipment, fabricated metal products, non-metallic mineral products and “other manufacturing, repair, and installation” are demanded for with a peak in 2028. The latter is related to installation and operation and maintenance of additional renewable energy capacities.

Public administration and some other sectors dependent on government consumption show a decelerated growth path compared to the business-as-usual scenario.

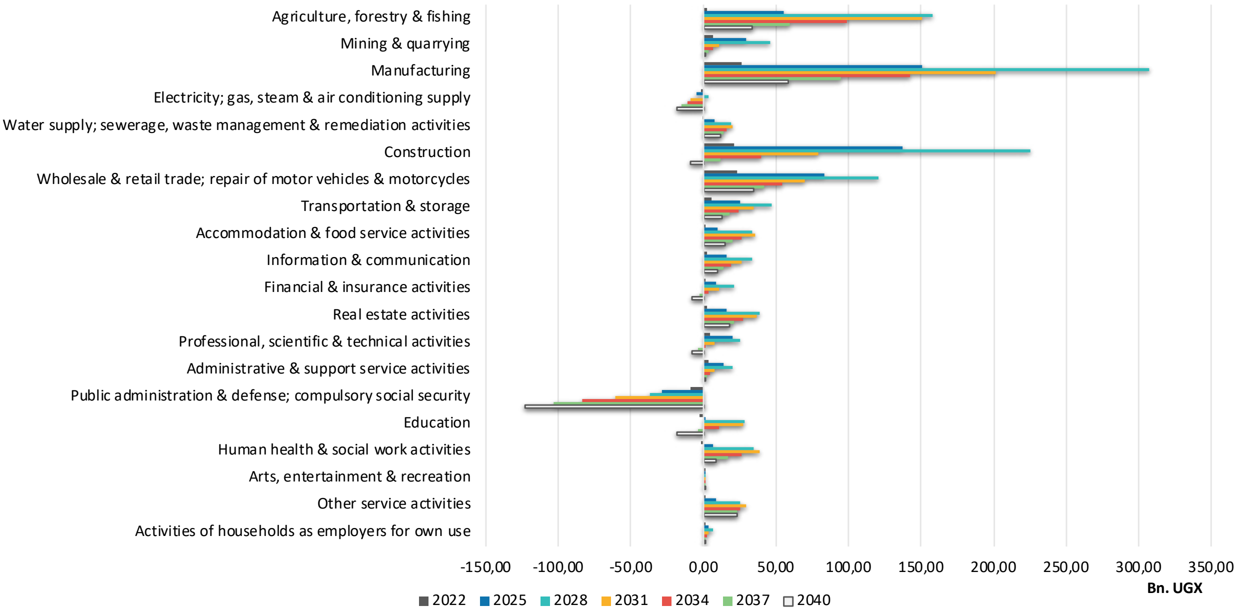

**Figure 19:** Real gross output by economic sectors (deviations from business-as-usual scenario in Bn. UGX, 2022–2040)

Source: e3.ug results

Sectoral employment follows production. Most of the additional jobs are created in agriculture and trade as indirect and induced effects increase demand in the said economic sectors and labour productivity is relatively low. Additional jobs are also created in the construction and other sectors which are directly affected from the expansion of RE.

In total, employment is up to 0.2% or 40,000 employed persons higher compared to the business-as-usual scenario and includes jobs directly and indirectly related to the renewable energy expansion and its supplier industries as well as induced jobs which are created through more income-related consumptions expenditures. Figure 20 shows the development of additional employment from 2022 to 2040: Until 2028, there is an increasing number of additionally employed persons. Afterwards, the expansion will decrease, as the investment stimulus will diminish.

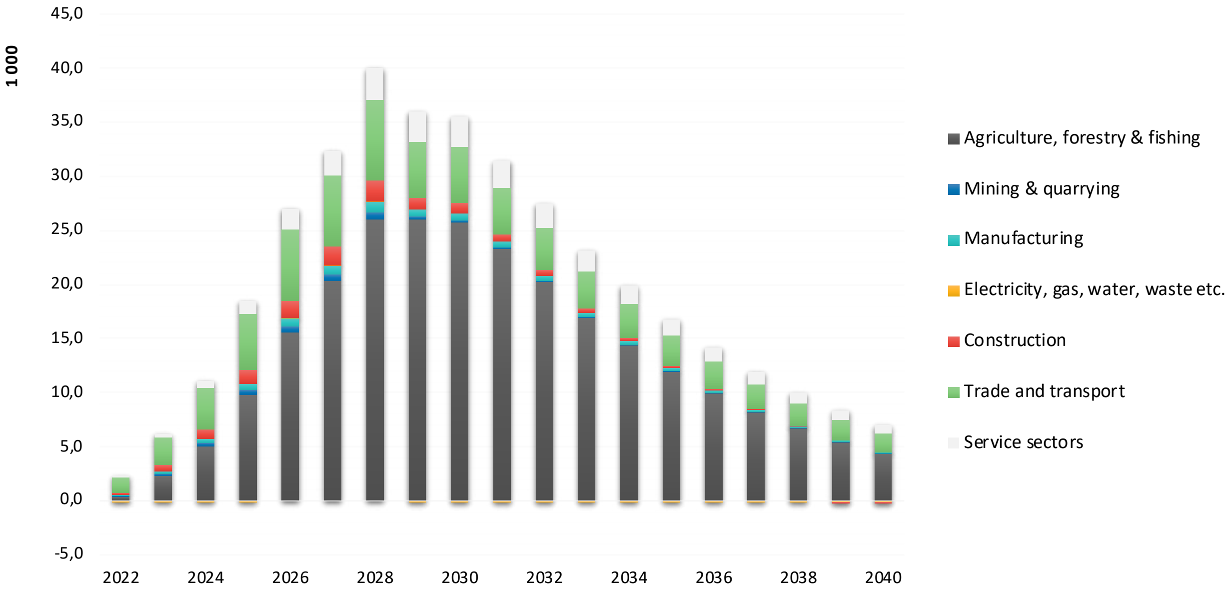

**Figure 20:** Employment by economic sectors (deviations from the business-as-usual scenario in 1,000 persons, 2022–2040)

Source: e3.ug results

The greater economic activity and better job situation is reflected in increasing prices but gains from higher wages outweigh this effect.

The impacts on the energy system are characterized by an increase of renewable energy electricity generating capacities. As the model e3.ug does not contain any energy system optimizing routines, resulting energy supply from power plants must be interpreted with care. It is anticipated that the power supply will be reliable and satisfies the electricity demand. It is also assumed that biomass is only used for electricity generation if all other non-biomass-based renewable energy such as hydro and PV are not sufficient.

As of 2022, electricity demand can be fully satisfied from the built-up non-biomass based renewable energy capacity. Over the simulation period, oil products, biomass and waste in electricity production can be replaced (see Figure 21).

This development contributes to less GHG emissions in the energy industries and forest land (see Figure 22). Carbon dioxide emissions from biomass combustion are recorded in forest land although emitted in other sectors such as the energy industry.

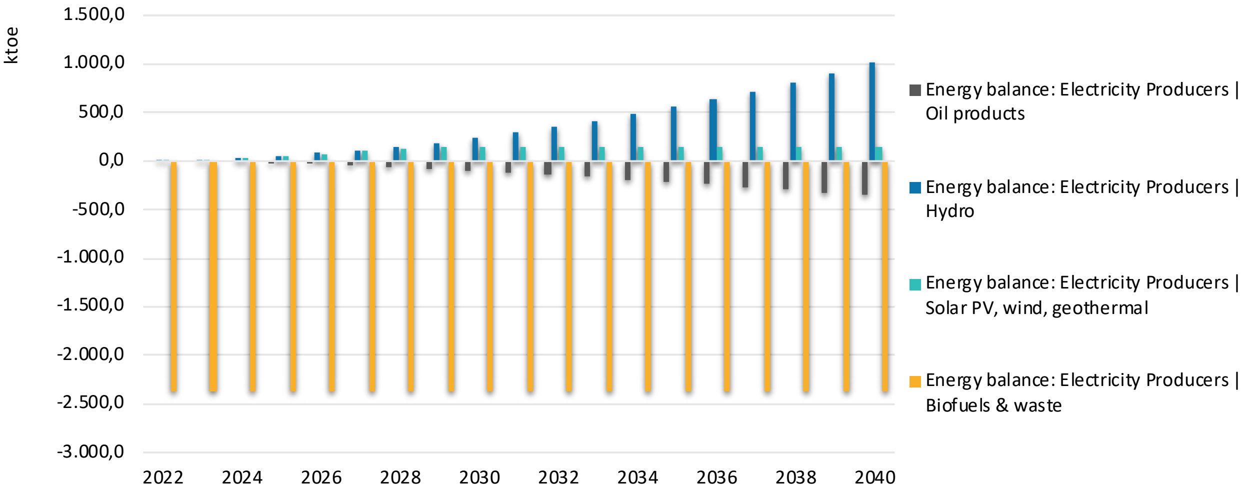

**Figure 21:** Energy inputs for electricity generation (deviations from the business-as-usual scenario in ktoe, 2022–2040)

Source: e3.ug results

All other sectors emit more GHG emissions due to higher economic activity. No additional mitigation measures such as energy efficiency improvements or an increased use of renewable energy for these sectors are presumed in this subscenario. This rebound effect curtails to a lesser extend the reduction of overall GHG emissions which decrease by 6,407 Gg $CO_2e$ resp. 4.7% by 2040.

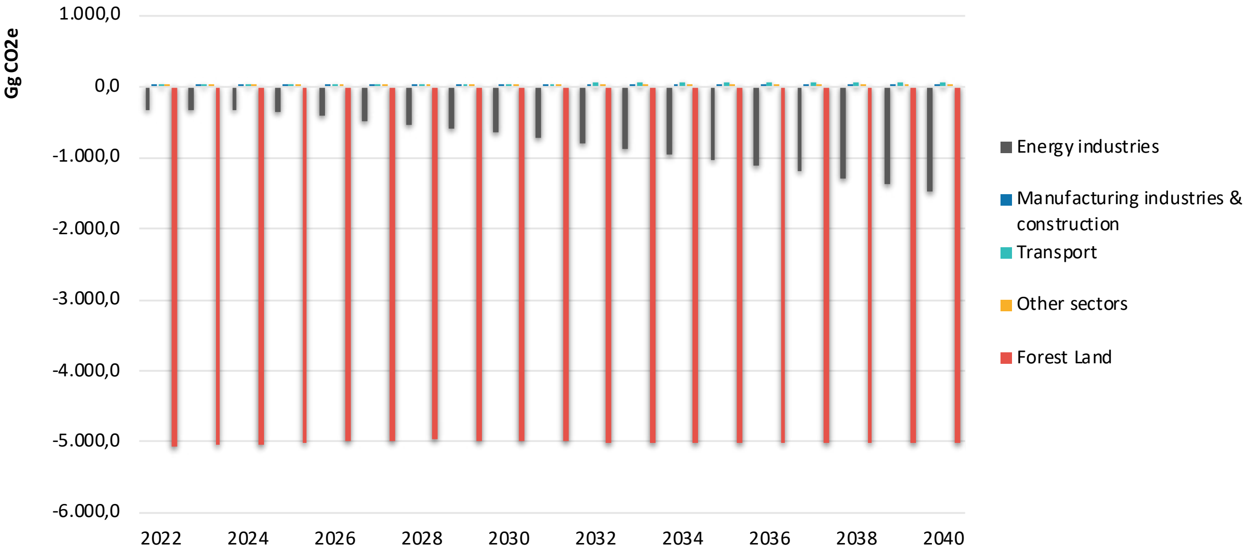

**Figure 22:** GHG emissions by sectors (deviations from the business-as-usual scenario in Gg $CO_2$ equivalents, 2022–2040)

Source: e3.ug results

### SUBSCENARIO 2: "ENERGY EFFICIENCY IMPROVEMENTS"

The macroeconomic and environmental effects are positive if energy efficiency improvements in the residential, industrial, commercial and energy sector are considered in a scenario. Electricity savings of 14% in commercial and residential sector and 16% in industrial sector can be achieved.

As there is no change assumed in the energy mix of consumers, electricity savings are limited and result in -61 ktoe compared to the business-as-usual scenario (top Figure 23). The industrial sector which consumes most electricity, contributes the most to the savings.

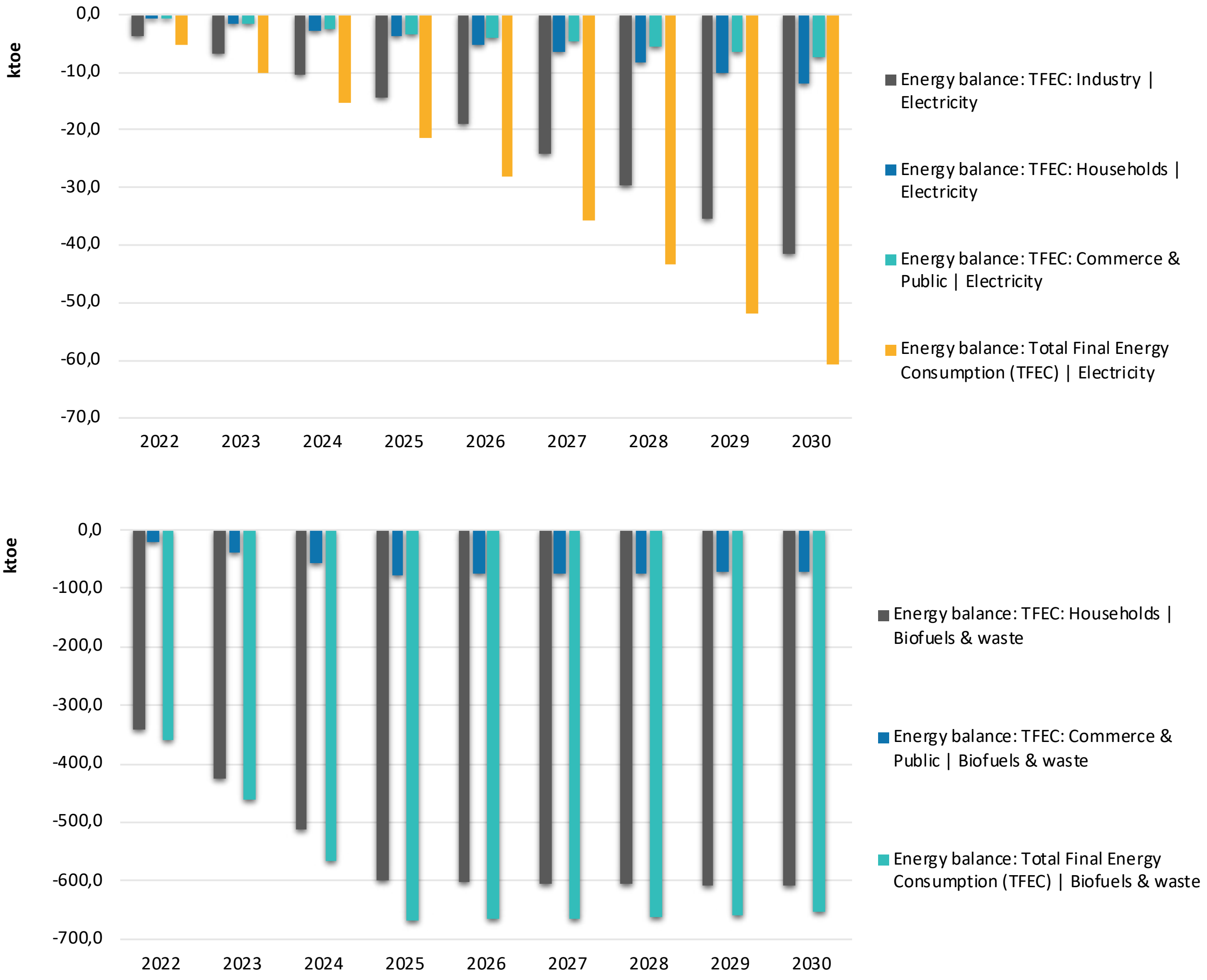

**Figure 23:** Electricity and biomass savings by sectors (deviations from the business-as-usual scenario in %, 2022–2030)

Source: e3.ug results

Additionally, 10% of the number of households and institutions (recorded in the commercial and public sectors) can reduce their biomass use by up to 6% (resp. 666 ktoe) due to improved cookstoves (bottom Figure 23). The biomass savings in the commercial sector are limited as only 10% of all 40,000 institutions are expected to save 35% of their biomass use (Harries et al. 2021, First Climate 2020).

Freed up electricity can be exported to neighbouring countries which would increase exports by up to 1.4% p.a. compared to BAU (see Figure 24).

Necessary investments and additional household expenditures for efficient electrical appliances and machinery as well as investments in the grid and improved cookstoves accelerate economic growth (+0.6% in 2030, Figure 24). Higher household expenditures for improved cookstoves and energy-efficient electrical appliances are assumed to be at the expense of "accommodation and food service activities".

The import dependency of the manufacturing sector dampens the positive economic development.

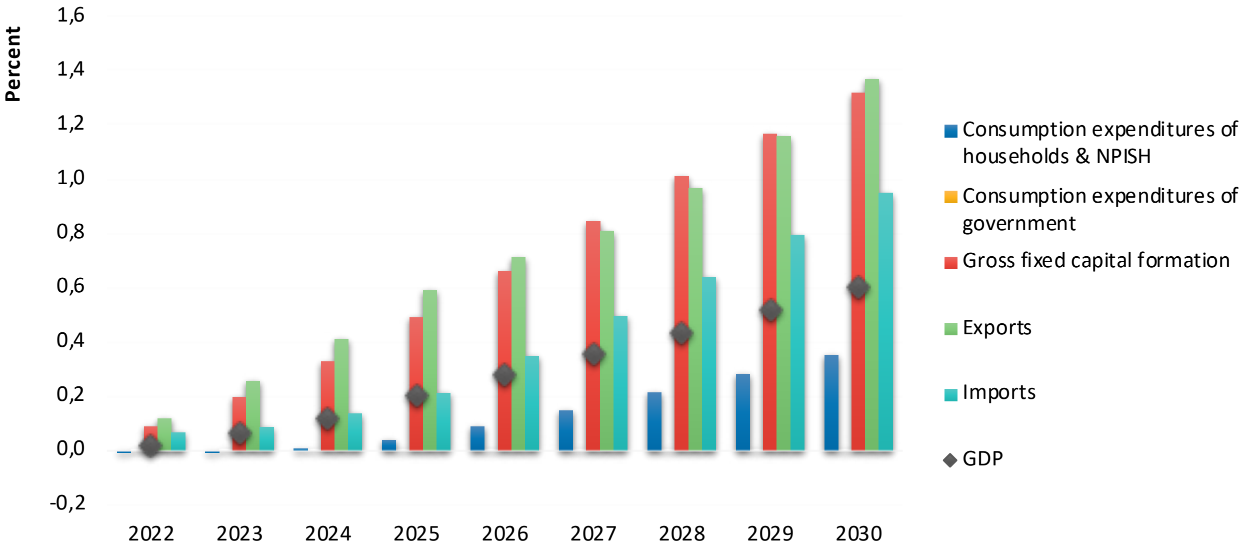

**Figure 24:** Real GDP and components (deviations from the business-as-usual scenario in %, 2022–2030)

Source: e3.ug results

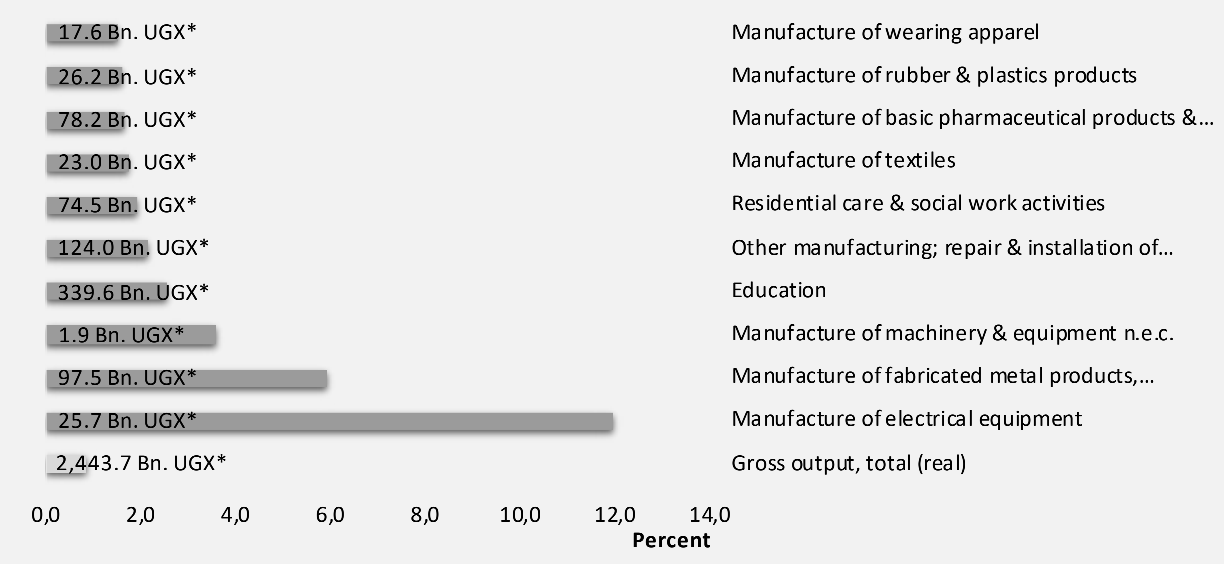

**Figure 25:** Real production by economic sectors (deviations from the business-as-usual scenario in % and Bn. UGX, 2030)

Source: e3.ug results

Production by economic sectors follows overall economic growth. The higher demand for energy-efficient machinery, electrical appliances and improved cookstoves can be seen in “manufacturing of electrical equipment”, “manufacturing of machinery” and “manufacturing in fabricated metal products” (Figure 25).

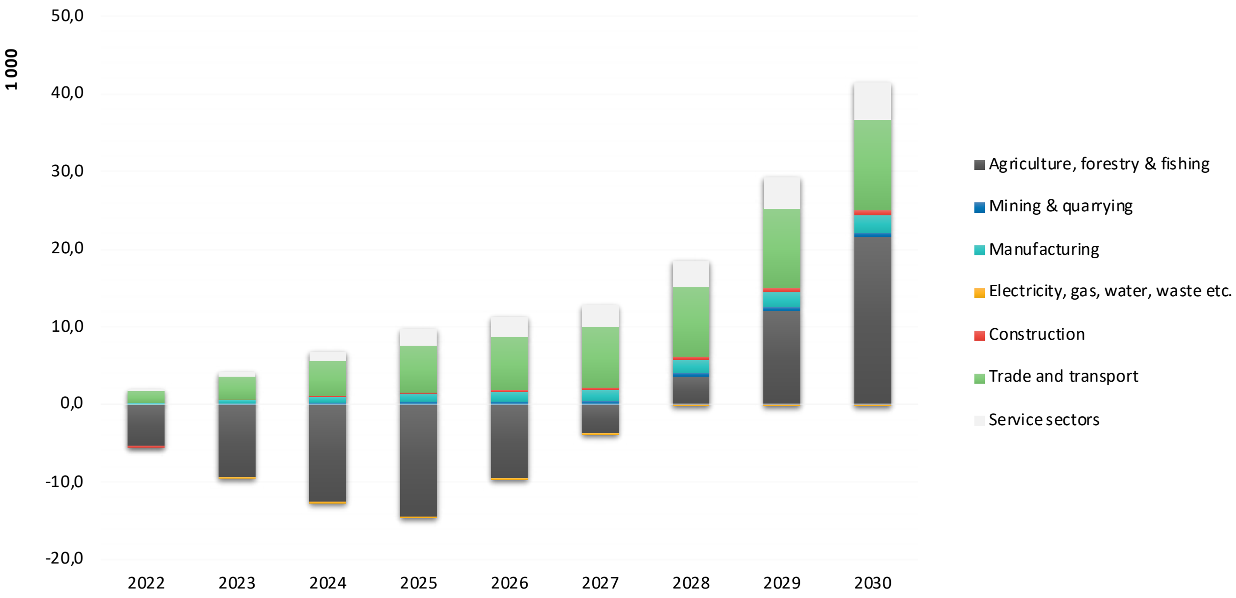

**Figure 26:** Employment by economic sectors (deviations from the business-as-usual scenario in 1,000 persons, 2022–2030)

Source: e3.ug results

In total, employment is increasing by 0.2% resp. 40,000 employed persons compared to the business-as-usual scenario in 2030 (Figure 39). Sectoral employment follows production considering sector-specific labour productivity. At the beginning of the simulation period, the employment level is lower than in the business-as-usual scenario. Less biomass use and less demand for "accommodation and food service activities" have a negative impact on production and thus employment in the sectors "agriculture, forestry and fishing" and "accommodation and food service activities". With a higher growth path and more income, this effect is reversed.

Employment in the manufacturing sector will increase by 2.2% by 2030 compared to the business-as-usual scenario. The increased domestic production of cookstoves creates even more jobs in the manufacturing sector than without this increased production.

By 2030, overall GHG emissions can be reduced by -2,405 Gg $CO_2e$ using improved cookstoves and energy-efficient electrical appliances. The saved $CO_2$ emissions can be seen in "other sectors" (including residential and commerce) and the forest land sector (Figure 27). The energy sector also contributes less to greenhouse gas emissions as the demand for charcoal is lower. GHG emissions from electricity production remain almost unchanged compared to the business-as-usual scenario.

Transport, manufacturing, and construction sectors show an increase in GHG emissions as electricity is not their main fuel and no efficiency improvement in biomass use is presumed for the industrial sector.

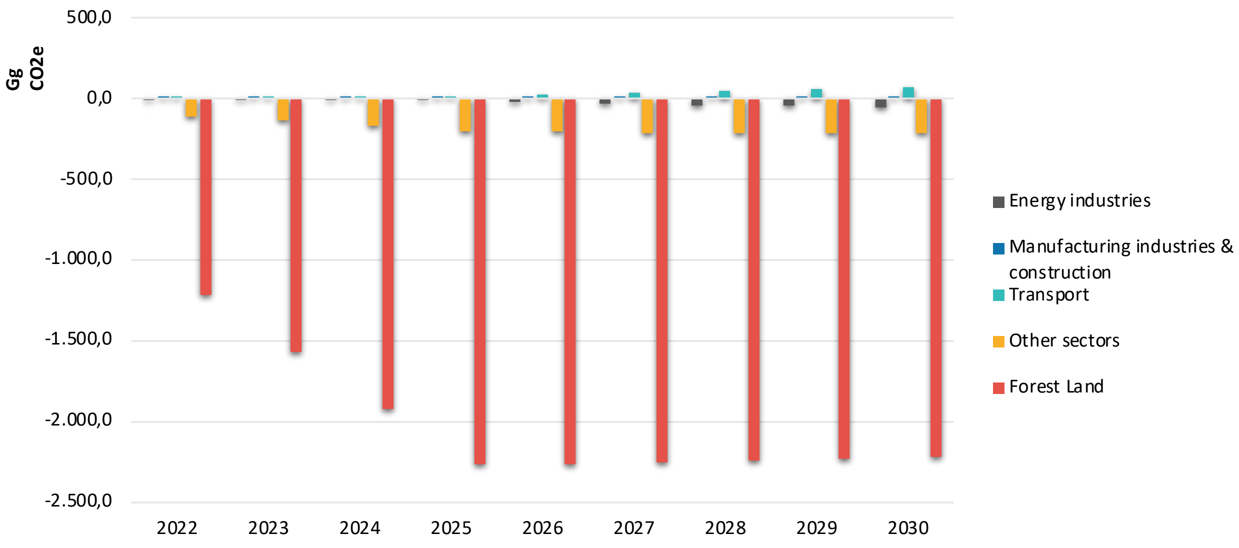

**Figure 27:** GHG emissions by sectors (deviations from the business-as-usual scenario in Gg $CO_2$ equivalents, 2022–2030)

Source: e3.ug results

### SUBSCENARIO 3: "CLEAN COOKING"

The switch from biomass to Liquefied Petroleum Gas (LPG) and electricity for cooking in the residential sector has an overall positive impact on the environment and the economy. In this subscenario, up to three million more households are using LPG cookstoves, and 1.4 Mn. more households are using electric cookstoves instead of the traditional biomass fired cookstoves. This leads to higher energy demand for electricity and LPG at the expense of biomass. Although households now have clean cooking opportunities, it is expected

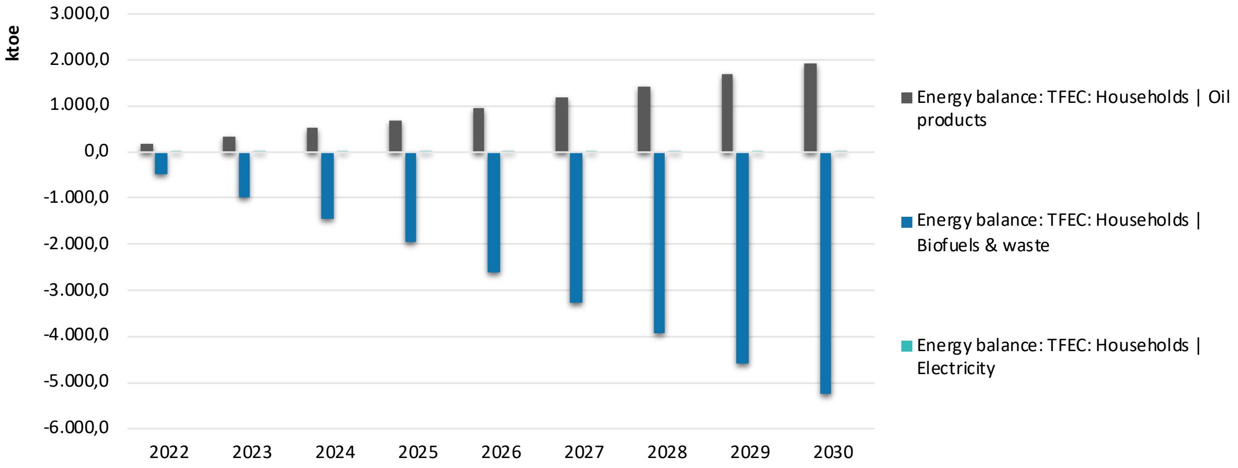

**Figure 28:** Energy demand by fuel for the residential sector (deviations from the business-as-usual scenario in ktoe, 2022–2030)

Source: e3.ug results

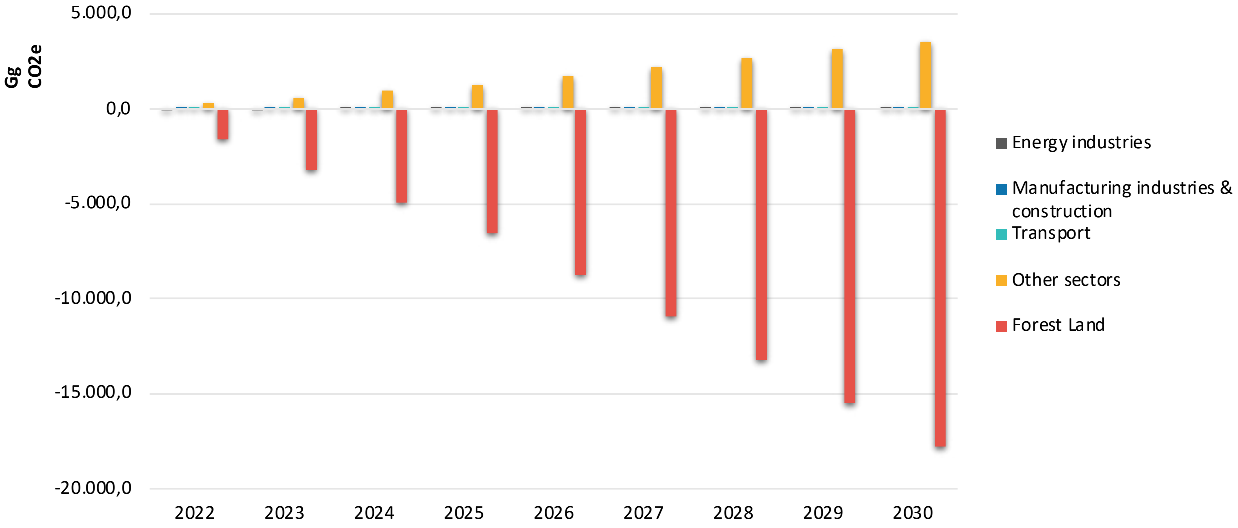

**Figure 29:** GHG emissions by sectors (deviations from the business-as-usual scenario in Gg $CO_2$ equivalents, 2022–2030)

Source: e3.ug results

that electric cookers are used only up to 50% of the time. Figure 28 depicts the final energy demand by fuel of the residential sector.

In a sensitivity analysis, it was anticipated that electric cookstoves are fully utilized. Consequently, electricity consumption further increases and displaces biomass consumption. As a result, GHG emissions decelerate further.

GHG emission can be reduced accordingly by up to 17,780 Gg $CO_2e$ by 2030, in particular in the forest land sector which includes the $CO_2$ emissions from cooking with biomass and charcoal production. The residential sector – which is part of "other sectors" – shows an increase of up to 3,578 Gg $CO_2e$ emission (Figure 29). The latter comprises the higher $CO_2$ emissions from LPG use which is intended in this scenario.

The switch to clean energy requires the purchase of new cookstoves and other fuels which is more expensive than the traditional way of cooking. Government subsidizes the upfront costs with 8 Bn. UGX as well as the electricity with a "cooking" tariff (MEMD 2022a; Kiiza 2021). In addition, it is assumed that foreign countries will partially finance the additional costs for LPG through carbon offsetting projects. For each tonne of $CO_2$ emissions reduction, it is assumed that foreign countries pay 100 USD which corresponds approximately to the $CO_2$ price in European emissions trading.

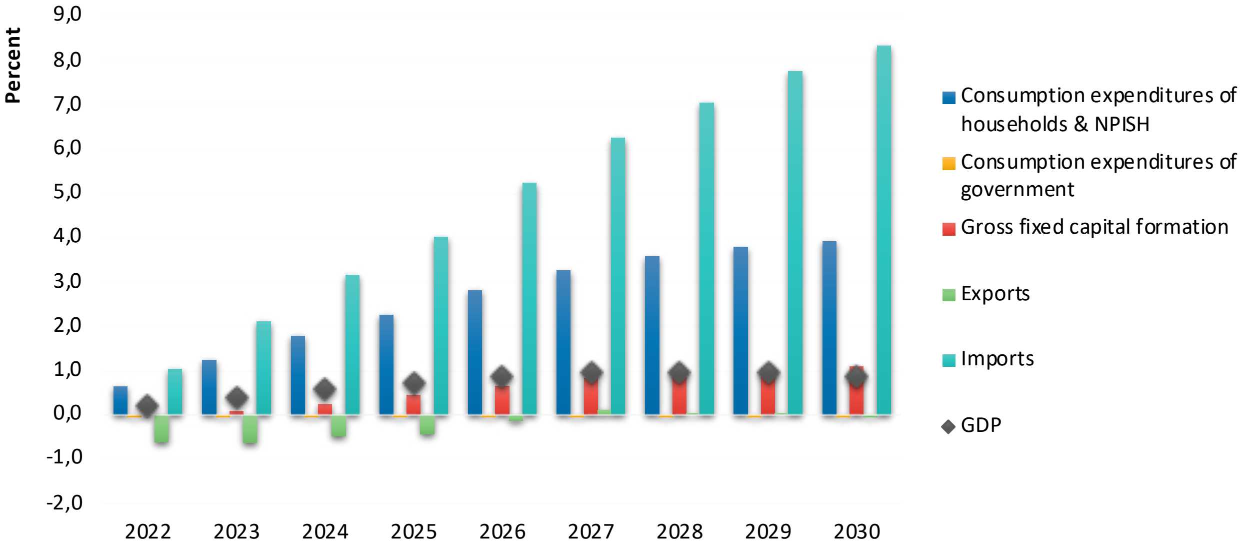

**Figure 30:** Real GDP and components (deviations from business-as-usual scenario in %, 2022–2030)

Source: e3.ug results

In total, household consumption expenditures are increasing by up to 3.9% p.a. in 2030 compared to the business-as-usual scenario (Figure 30). The additional costs for the households are assumed to be at the expense of non-essential goods such as "accommodation and food service activities".

Due to the high import dependency of electrical equipment (to which electric cookstoves belong) and "coke and refined products", imports are increasing by up to 8.3% p.a. compared to the business-as-usual scenario. Overall, the economic growth is improved and up to 0.9% p.a. higher.

**Figure 31:** Real gross output by economic sectors (deviations from the business-as-usual scenario in Bn. UGX, 2022–2030)

Source: e3.ug results

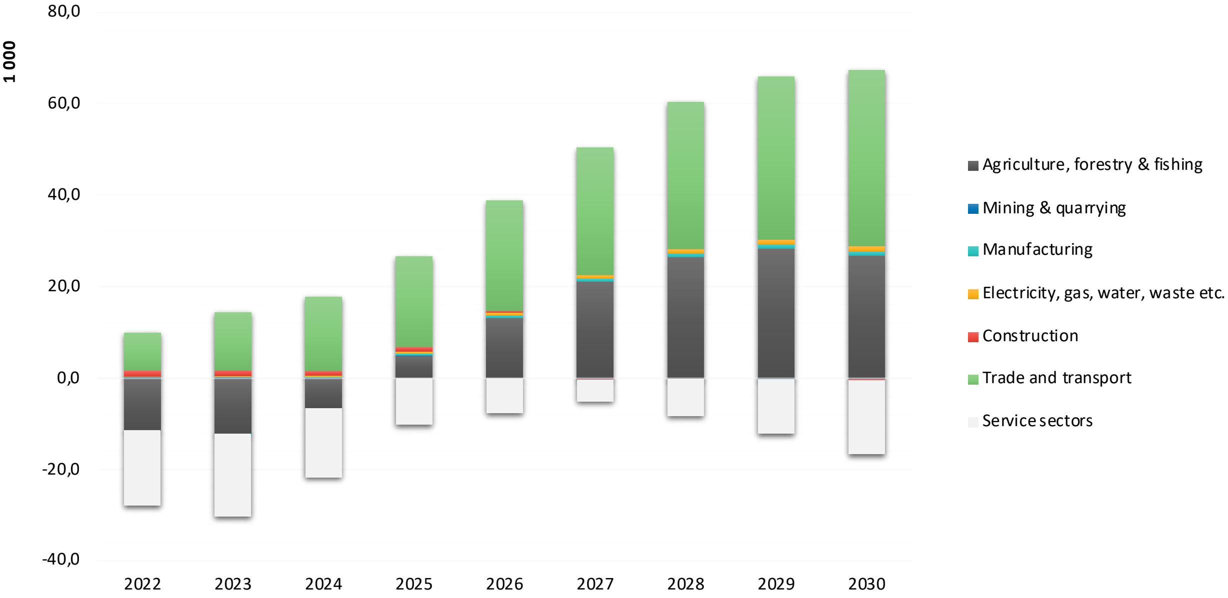

**Figure 32:** Employment by economic sectors (deviations from the business-as-usual scenario in 1,000 persons, 2022–2030)

Source: e3.ug results

The macroeconomic development is also reflected at the sectoral level. Various economic sectors can profit from the overall development, amongst others manufacturing, trade and electricity suppliers (Figure 31). "Accommodation and food service activities" are at a lower growth path compared to the business-as-usual scenario as it is expected that households will spend less money for non-essential services. At the beginning of the simulation period, also the sector "agriculture, forestry, fishing" shows a weakened production as the domestic production of firewood is negatively affected from the intended switch to clean cooking technologies. In subsequent years, income-induced effects prevail which increases household consumption benefiting the aforementioned sector.A similar effect shows Figure 32 for employment by sectors. "Accommodation and food service activities", which is part of "service sector", shows an expected lower employment level. Also, the sector "agriculture, forestry, fishing" has less employed persons at the beginning of simulation period, as this sector is an important supplier for "accommodation and food service activities". The analysis of so-called indirect effects is one of the benefits of the underlying IO modelling approach of the DIOM-X based E3 model.

### SCENARIO "CURRENT ENERGY POLICY PLANNING"

Combining the previous subscenarios leads to an energy transition scenario covering the expansion of RE, energy efficiency and clean cooking. The impacts for the macroeconomy and environment are positive.

The economic growth accelerates and reaches an up to 1.9% higher GDP per year compared to the business-as-usual scenario. Investments in renewable energy and energy efficiency particularly contribute to growth. Exports of the saved electricity are another driving factor. However, increasing imports for manufactured goods and fuels have a dampening effect on the economy (Figure 33).

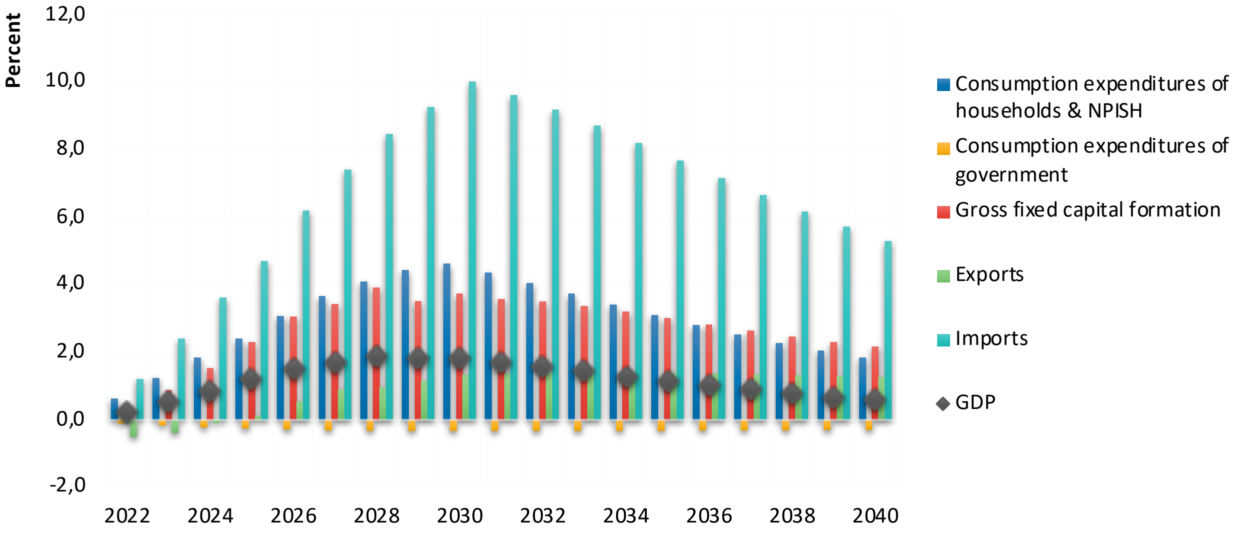

**Figure 33:** Real GDP and components (deviations from the business-as-usual scenario in %, 2022–2040)

Source: e3.ug results

All sectors benefiting from energy efficiency improvements can reduce their energy costs. However, upfront costs are a hurdle – in particular for households – and need to be supported by the government and carbon offsetting projects to make them more affordable.

Households profit from more employment and income which leads to higher household consumption expenditures.

Up to 129,000 additional jobs are created compared to the business-as-usual scenario (see Figure 34). Especially the sectors "trade and transport" as well as "agriculture, forestry and fishing" profit as they are quite labour intensive. To a lesser extent, there are also more employed persons in the manufacturing, energy, and construction sectors. Investments in renewable energy and efficient appliances increase the demand for electrical equipment, machinery, non-mineral, and metal products but also for goods and services during operation and maintenance.

Although government partially subsidises upfront cost for clean cookstoves and provides a "cooking tariff", households face additional costs which are assumed to be at the expense of "accommodation and food service activities". This will imply a lower level of employment in this sector.

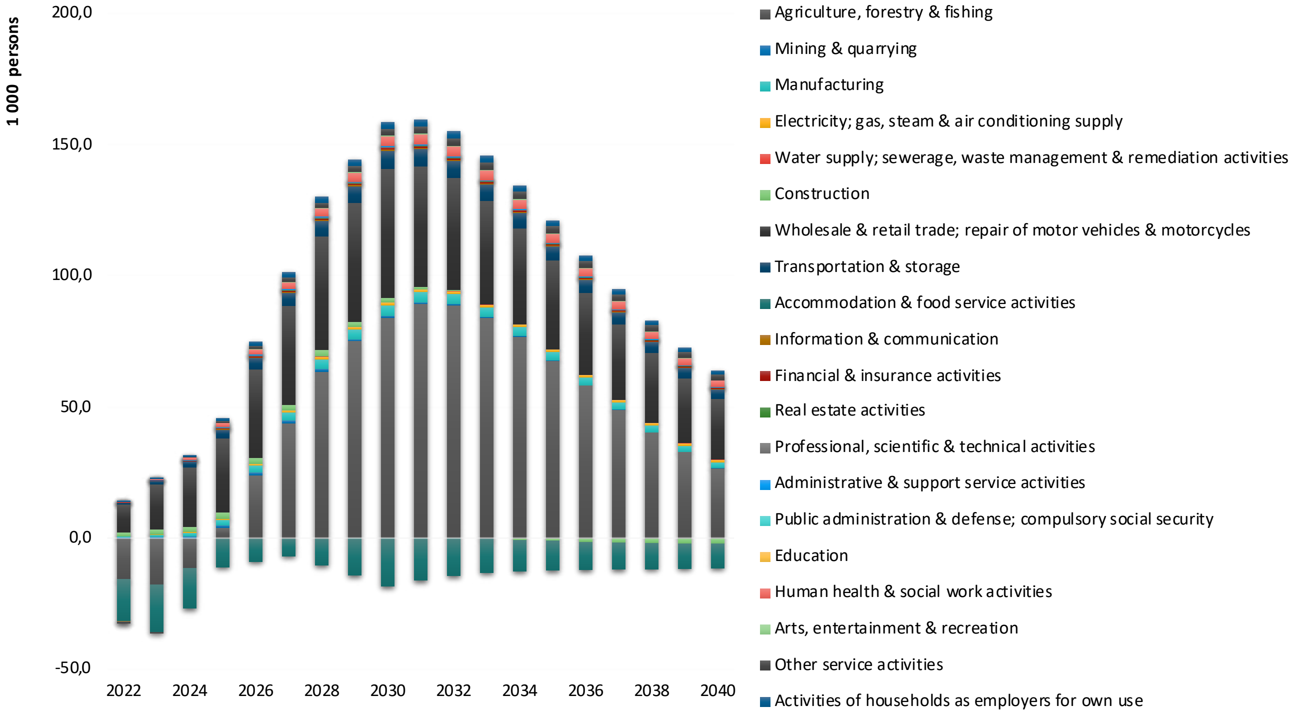

**Figure 34:** Employment by economic sectors (deviations from the business-as-usual scenario in 1,000 persons, 2022–2040)

Source: e3.ug results

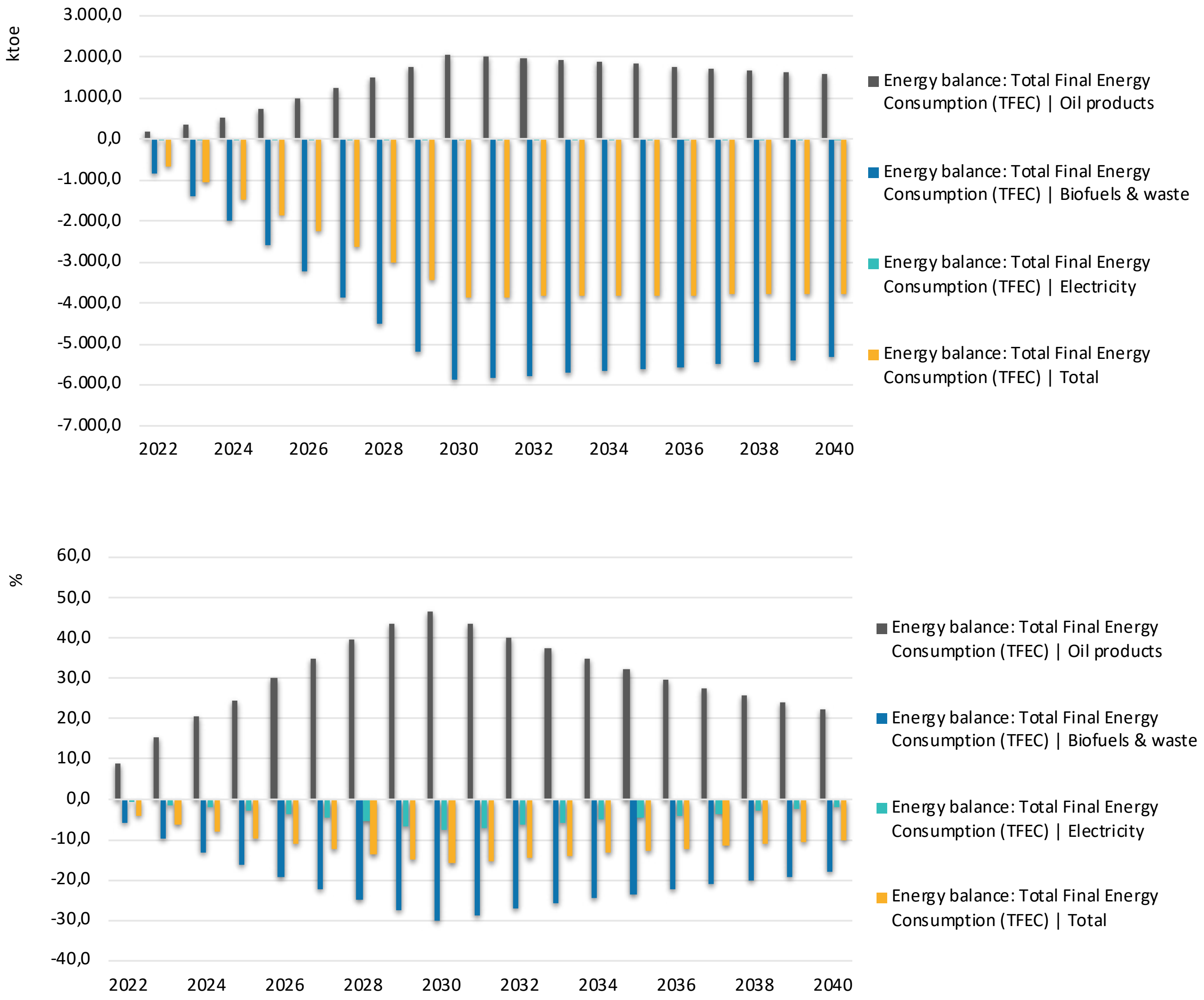

**Figure 35:** Total final energy consumption by fuels (deviations from the business-as-usual scenario in ktoe (top figure) and % (bottom figure), 2022–2040)

Source: e3.ug results

For the environment, the impacts are also positive. Efficiency improvements can reduce the total final energy consumption by up to 16% resp. 3,880 ktoe (see Figure 35). While energy demand for biomass and electricity can be reduced, demand for oil products is increasing. This is due to the situation that LPG use for cooking is intended but also the transport sector increases fuel consumption due to higher economic activity.

The expansion of renewable energy as well as the replacement of biomass by LPG and electricity changes the energy inputs in the energy sector. Less use of biomass for cooking reduces charcoal production and thus, the need for firewood.

More non-biomass-based renewable energy reduces the use of oil products and biomass in electricity generation. The results which are presented here are subject to the assumption that electricity demand is satisfied first by non-biomass-based RE, then by biomass and finally by fossil fuels. Figure 36 shows that electricity demand can be fully satisfied with non-biomass-based RE.

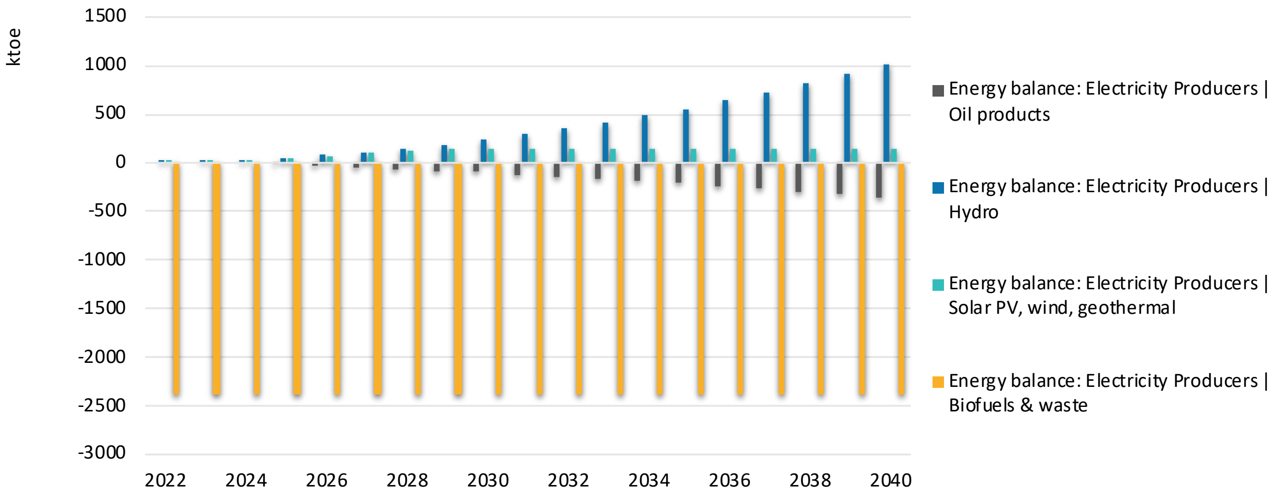

**Figure 36:** Energy inputs for electricity generation (deviations from the business-as-usual scenario in ktoe, 2022–2040)

Source: e3.ug results

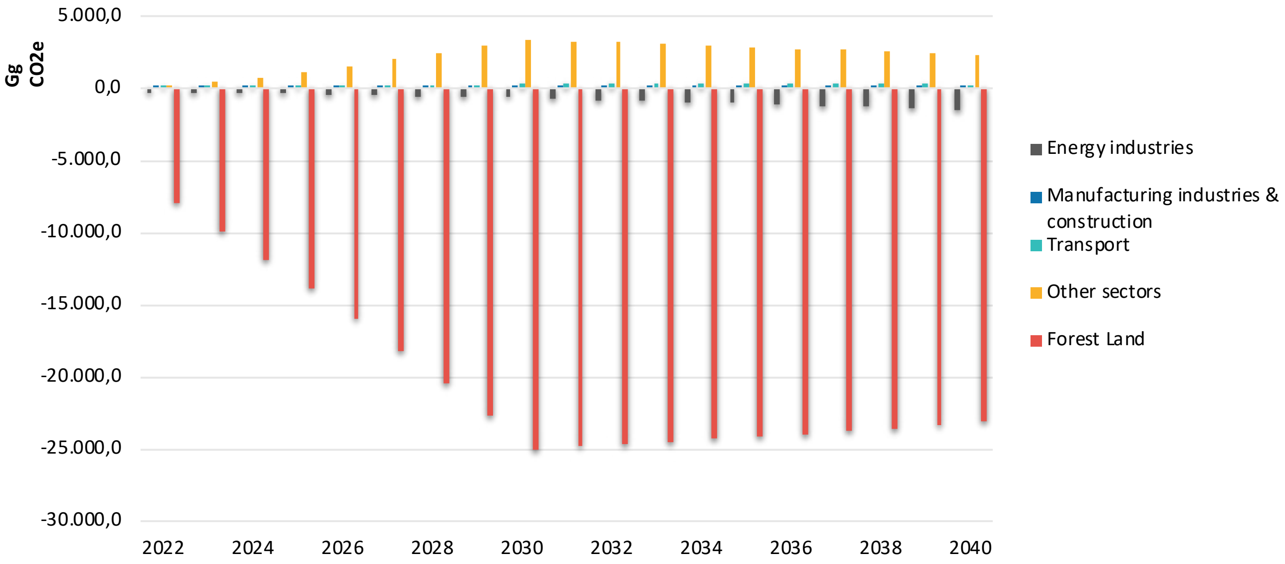

**Figure 37:** GHG emissions by sectors (deviations from the business-as-usual scenario in Gg $CO_2$ equivalents, 2022–2040)

Source: e3.ug results

The results for the GHG emissions are shown in Figure 37. As $CO_2$ emissions from biomass combustion are included in the forest land sector – regardless of the sector by which they were caused – this sector shows the greatest GHG emissions reduction. Avoided methane and nitrous oxide emissions from combustion are attributed to the originating sectors.

Apart from the energy and forest land sector, all other sectors show an increase in GHG emissions as they are using oil products such as the transport sector or LPG such as the residential sector.

In summary, this scenario has positive impacts for the economy, employment, and the environment. Biomass use is reduced by the energy and residential sectors which reduces households' air pollution and limits deforestation. Efficiency measures save energy and decrease the energy bill. However, upfront costs can be high and financial support is needed in particular for households to incentivize the switch to clean energy and energy saving appliances. Government and international carbon offsetting projects help to support national climate protection measures.

Trade balance can be improved by exporting the saved electricity to neighbouring countries but the import dependency from fossil fuels overcompensates this effect. If local production is promoted, trade balance and the economic and employment effects could be further improved.

Rebound effects curtail the reduction of GHG emissions to a limited extend. Thus, the use of renewable energy and energy efficiency measures should be promoted in all sectors.

## CONCLUSIONS

The scenarios for the energy transition in Uganda calculated with the e3.ug model are comparable to other studies such as Harries et al. (2021) and La Rue Can et al. (2017). The latter study only addresses electrical energy efficiency in several sectors, while Harries et al. (2021) extend their analyses to energy efficiency measures and renewable energy expansion.

Harries et al. (2021) evaluates the future GHG emissions pathways without (BAU) and with mitigation options to update Uganda's NDCs and to develop a LTS for Uganda. The assessment of future GHG emission pathways comprises all sectors according to the GHG inventory of UNFCCC (e. g., energy, industrial processes, AFOLU, waste). The scenario analyses are conducted with Low Emissions Analysis Platform (LEAP) and Excel based models.

In contrast to the scenario analyses with the Excel-based e3.ug model, Harries et al. (2021) only focuses on very detailed GHG emissions projection, while e3.ug also analyses the macroeconomic impacts of the energy transition scenarios but only GHG emissions ($CO_2$, $CH_4$, $N_2O$) from fuel combustion activities and the forest land sector. Similarly, La Rue Can et al. (2017), focus on sector-specific analysis of potential electricity savings and do not consider macroeconomic impacts.

In this respect, the e3.ug model complements the models and studies mentioned above as it enables to evaluate the economy-wide impacts of mitigation measures covering direct, indirect, and income-induced effects. The IO modelling approach which shows the structure of Uganda's economy and their intersectoral linkages, helps to identify 'winners' and 'losers' of policy measures. For example, investments in renewable energy stimulates affected economic activities and in turn also industries along the value chain. Due to the high import dependencies of manufacturing sectors, the benefits for the macroeconomy are limited as increasing imports dampen economic growth.

Furthermore, the integrated modelling approach of the three E's allows to detect rebound effects stemming from additional economic activity that may curtail the expected impacts on emissions.

The scenario results of the energy transition scenarios are positive for the economy – in terms of economic growth and employment – and the environment (see also (MEMD 2023a, 2023b)). Results for the economy could be even better if domestic production is promoted, and financial support can be attracted from international carbon offsetting projects and climate finance promises of developed countries at the COP27.

Energy efficiency improvements and the expansion of renewable energy are important cornerstones to reduce biomass use. These measures preserve nature by limiting deforestation and retaining carbon sinks. Moreover, this has positive effects on human health by reducing air pollution from cooking.

The mitigation measures analysed with e3.ug are not exhaustive which results in unwanted effects. For example, in all scenarios the transport sector shows higher emissions compared to the business-as-usual scenario. To avoid the so-called rebound-effects, further measures should be taken to support both efficiency gains and the use of renewable energy in other sectors.

# 4 LESSONS LEARNED

## FUTURE COOPERATION AND FUTURE APPLICATIONS OF E3.UG

### REGULAR UPDATES OF E3.UG MODEL

For evidence-based analyses, it is important that quantitative models used are up to date to provide policy makers with most recent data and projections. One key feature of the Excel-based e3.ug model is the data-driven approach. Every E3 component is modelled in detail based on annual data from official statistics which is usually updated yearly. Thus, it is advisable to update the historical data set once a year.

The model is not a "black-box". It includes the data, model code and results combined in one Excel workbook. Thus, updating the model is straightforward but several steps must be taken as described in (Großmann et al. 2022, see Figure 38).

It is recommended to share the workload among experts as the updating process is time consuming and requires different expertise. A group of specialists in data collection and processing may take over the responsibility to update the historical data set of the model. For example, MEMD may take over the update of energy data and MWE the update of the GHG emission data. This work could be supported by the national modelling consultants. Close contact to UBOS and other relevant data providers such as ERA is essential.

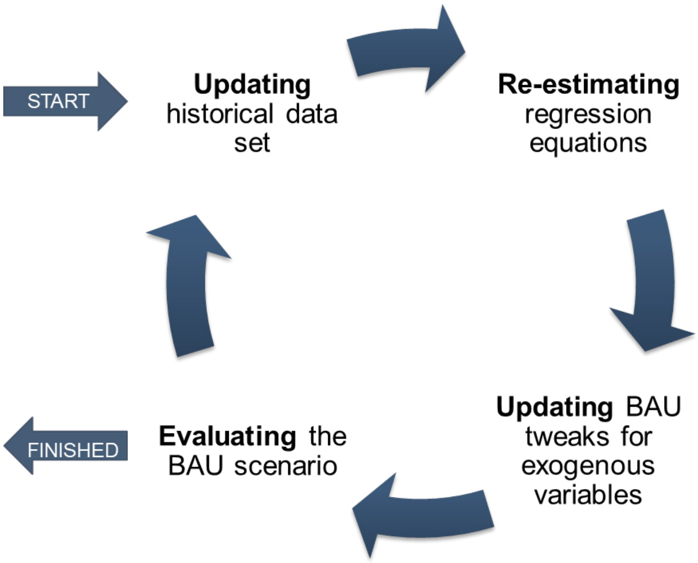

**Figure 38:** Updating the e3.ug model data set – steps to be taken

Source: GWS

During that process, experts may review if data currently received from international sources (e. g., employment data) can be replaced by Ugandan statistics. Furthermore, it should be reviewed if more sufficient time series data (e. g., production price indices) are provided by statistics which could improve the quality of the regressions.

After the historical data set is updated, econometricians may reestimate the regression equations of the model. Subsequently, exogenously given model variables may be reworked according to new findings. As a result of this updating process, an updated business-as-usual scenario until 2050 must be created. An important cornerstone is the joint evaluation of the business-as-usual scenario by local scientific experts and policy makers. Once this process is finalized, the model can be applied to simulate certain policies and their impacts on the macroeconomy. Contact to key persons is a prerequisite to raise the awareness about the model and its use.

### REGULAR APPLICATIONS OF E3.UG MODEL

The Excel model provides a mechanism for easy and fast computation of scenarios ("what-if" analysis) which is the main purpose of this tool. The tool allows for easy implementation of scenario assumptions, calculation, and evaluation of the macroeconomic impacts of own scenarios. Preprepared evaluation tools are part of the Excel model and can be easily applied and further customized by the user.

The future application of the e3.ug model requires regular contact between the e3.ug model owner MEMD, other ministries who need support with macroeconomic modelling to answer key policy questions and persons / institutions who are updating and upgrading the model.

The main purpose of the current e3.ug model is to evaluate mitigation scenarios such as the expansion of renewable energy and EE. During the training sessions, several scenarios were presented and the sections 3.2.1–3.2.4 provide more examples of what has been achieved so far. Further scenarios can be calculated by varying, for example, the energy efficiency assumptions which could be less and even more ambitious according to the Energy Efficiency Strategy of Uganda (La Rue Can et al. 2017).

Dissemination activities to increase the awareness about the existence of the e3.ug model and application opportunities may comprise policy briefs (see for example (MEMD 2023a, 2023b)), regular meetings with local field experts and with experts from abroad by presenting the model and results from policy scenarios at international expert group meetings and conferences.

To avoid the negative impacts of brain-drain within the modelling institution, internal trainings on model update, upgrade and use in particular for new members are recommended. The national modelling consultants might be appropriate persons to train new members. The international consultants are also willing to support this process.

### POSSIBLE EXTENSIONS OF E3.UG MODEL

The model can also be expanded in many ways to give more detailed insights into the economic development or to investigate other key questions of policymakers such as energy efficiency improvements in the building or transport sector as well as the economic impacts of climate change (e. g., droughts) and adaptation measures (e. g., investing in irrigation systems). The following aspects provide exemplary upgrading options. One option is the integration of detailed national accounts which allows for modelling the complete economic circuit and the monetary flows from production to consumption. The system of national accounts (SNA) shows the revenues and expenditures of the institutional sectors such as government and households. An important variable in the SNA is disposable income, which is influenced by both the current employment status and the redistributive activities of the government through taxes and subsidies. With more detailed data, the simplified determination of household consumption expenditures can be improved.

The labour market could be modelled in more detail. So far, employment data are only available for 21 economic sectors which is less compared to the economic sectors of the IOT. Wages by economic activities should be introduced once they become available as time series from statistics to be better informed about the income opportunities of persons employed in certain economic sectors. This is also an important aspect for a distributional analysis.

Furthermore, qualification levels of employed persons could be introduced to detect the necessary qualifications (low, medium, and high) in several economic sectors. The inclusion of gender and wages by economic sectors may help to identify the poverty risk of different groups.

In Uganda, agriculture and forestry play an important role not only for the economy but also for the development of GHG emissions and carbon sinks. A more detailed modelling of the AFOLU sector would help to take GHG emissions and the effects from mitigation actions into account not yet covered such as emissions from livestock.

## COMPLIANCE OF THE MODEL WITH THE U4RIA PRINCIPLES

In general, a model is a simplified presentation of a (real-world) counterpart. Simplification reduces complexity, but at the same time omits details. Consequently, a model suits a limited set of applications which have been identified at the design stage.

If an economic model becomes part of policy device processes, it is extremely important that full access to all model information is ensured, including historic and projected data, meta information about the database (e. g., data sources, date of revision, etc.), model code and assumptions. Without transparent access to these information, interpretation of model results as well as possible applications and limits can hardly be verified.

In recent years, the importance of transparency in modelling finds more and more attention. One example is the U4RIA initiative[13] which has been created to improve transparency of energy modelling for policy support by introducing a set of governance principles that should accompany the mathematical models.

The E3 DIOM-X-based modelling approach by design takes the importance of transparency into account: The models are self-contained by storing all data, meta data, model, framework code and results in one Excel workbook which allows for unrestricted access to the full set of information ("white box" approach). Other cornerstones are promoting close contact between national and international experts as well as transfer of model ownership and intense capacity building.

This section describes the result of validating the E3 DIOM-X modelling approach against the set of U4RIA principles as well as the benefits and barriers which arose from applying the principles to the model building process.

All in all, the U4RIA initiative promotes the following seven principles that have been applied throughout the process of building and using the e3.ug model:

**UBUNTU:** The Ubuntu term stands for "I am because you are" and relates to the various roles in an organizational workflow and their relations. The principle is addressed by promoting close collaboration between national and international experts via regular expert meetings, dissemination of related information (i.e., e3.ug model handbook, policy briefs), intense capacity building as well as proofreading of key model outputs (scenario results and policy briefs).

**RETRIEVABILITY:** The principle addresses functional retrievability. Although an E3 DIOM-X model (mostly) relies on official statistics which is publicly available, the model is distributed with all unprocessed data files that were used to build the model database. This ensures that information can be verified even if (parts of) the original data is not publicly accessible anymore. For each variable, additional meta information (e. g., data source, contact person) is stored in the e3.ug model workbook.

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[13] https://climatecompatiblegrowth.com/u4ria/

**REUSABILITY:** Reusability is often constrained by common licensing issues. The E3 DIOM-X modelling approach promotes the use of publicly available data wherever possible retrieved from official statistics and involved partners. Exceptions need to be justified and documented. Storage and processing of all data in MS Excel data format limits incompatibilities with respect to future use and dissemination.

**REPEATABILITY:** This principle promotes a user-friendly digital workflow to ensure repeatability. The well-known Excel-based interface of DIOM-X models addresses this issue.

**RECONSTRUCTABILITY:** Transparency requires that all information starting from input data up to scenario results need to be reconstructable. DIOM-X-based models contain dedicated worksheets for the different kinds of information (i.e., model dataset, historical and projected data, scenario assumptions) with meta-data further describing the respective data.

**INTEROPERABILITY:** This principle requires scenario output ("results") to be stored in a way that allows other processes to access the data for broader integration. The DIOM-X framework stores all information in MS Excel format which is compatible with most applications.

**AUDITABILITY:** If an economic model becomes part of policy processes, auditability is important to address common governance principles. Application of the other principles – which are addressed by the DIOM-X modelling approach – ensures that all information is available on request at any time.

The aforementioned principles further enforce a "white box" approach which increases transparency and confidence in evidence-based policy processes. The DIOM-X modelling approach simplifies the application of U4RIA principles and allows for easier stakeholder engagement at all levels (data set, model assumptions, scenario design).

In practice, some hurdles may remain. Some policies may require of classified data which limits transparency and complicates model dissemination. Increased transparency often requires additional workload for more detailed documentation and capacity building burdening the budget. Some involved parties (policy-makers, field experts, research institutes) usually have limited capacities which may hinder the application of U4RIA principles.

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